GL14 Continued

decision, and the Court having directed that a peremptory writ of mandate issue in this proceeding,

IT IS SO ORDERED that:

1. Judgment granting a writ of mandate be entered in favor of all the above-referenced Petitioners' in this proceeding. Judgment is so entered because the Court finds that Respondents committed a prejudicial abuse of discretion by failing to prepare a legally adequate Environmental Impact Report and did not comply with the California Environmental Quality Act ("CEQA"), Public Resources Code, section 21000 *et seq*. The basis for the Judgment is set forth in the attached Minute Order ("Ruling After Hearing"), which is incorporated by reference.

2. A peremptory of writ of mandate directed to Respondents California Department of Transportation and Director Will Kempton shall issue under seal of this Court, ordering Respondents to do all of the following:

a. Within 30 days from service of this writ of mandate, Respondents shall vacate and set aside the June 21, 2007, certification of the Final Environmental Impact Report for the Sacramento 50 Bus/Carpool Lanes and Community Enhancement Project, and the June 21, 2007, approval of the Sacramento 50 Bus/Carpool Lanes and Community Enhancement Project ("Project").

b. Respondents shall not reapprove the Project unless and until Respondents have certified an environmental impact report that complies with CEQA and the CEQA Guidelines, and otherwise complied with CEQA.

c. Respondents and their agents shall suspend any and all activities to approve and implement the Project that could result in adverse change or alteration to the physical environment, until this Court determines that Respondents have taken the actions specified herein to bring their approval of the Project into compliance with CEQA.

d. Respondents shall file an initial return to the peremptory writ of mandate within 30 days of service. Respondents shall file a supplemental return to the writ of mandate after they have certified an EIR for the Project, or after they have determined not to reapprove

[PROPOSED] JUDGMENT GRANTING PETITION FOR WRIT OF MANDATE 2

GL14 Continued

the Project. The Court shall retain jurisdiction over Respondents' proceedings by way of the return to the peremptory writ of mandate until the Court has determined that Respondents have complied with CEQA.

3. Petitioners are awarded their costs of suit upon appropriate application.

4. The Court shall retain jurisdiction for any motion for an award of attorney's fees.

DATED: ~~July __, 2008~~ August 12, 2008

The Honorable Timothy Frawley
Judge of the Superior Court

Approved as to Form:

DATED: July 24, 2008

CALIFORNIA DEPARTMENT OF TRANSPORTATION

By M Keck
Martin Keck
Attorney for Respondents
California Department of Transportation and Director Will Kempton

[PROPOSED] JUDGMENT GRANTING PETITION FOR WRIT OF MANDATE 3

GL14 Continued

SUPERIOR COURT OF CALIFORNIA,
COUNTY OF SACRAMENTO
GORDON D SCHABER COURTHOUSE
MINUTE ORDER

Date: 07/15/2008 Time: 11:51:50 AM Dept: 29

Judicial Officer Presiding: Judge Timothy Frawley
Clerk: L. Young

Bailiff/Court Attendant: NONE
ERM:
Reporter: NONE,

Case Init. Date: 11/12/2007

Case No: 07CS00967 Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA DEPT OF TRANSPORT. ET AL

Case Category: Civil - Unlimited

Causal Document & Date Filed:

Appearances:

RULING AFTER HEARING

Petitioners Environmental Council of Sacramento and Neighbors Advocating Sustainable Transportation ("Petitioners") challenge Respondent California Department of Transportation's ("Caltrans") June 21, 2007, approval and certification of a Final Environmental Impact Report ("Final EIR") for the Sacramento 50 Bus/Carpool Lanes and Community Enhancement Project under the California Environmental Quality Act ("CEQA"). Petitioners seek a writ of mandate directing Caltrans to set aside its certification of the EIR and approval of the Project.

The Project, as approved, proposes to build approximately 13 miles of High Occupancy Vehicle ("HOV") lanes, in the east-bound and west-bound directions, within the existing median of U.S. Highway 50 from Sunrise Boulevard to Watt Avenue, plus various transportation-related "community enhancements" related to the highway improvements. Currently, within the Project boundaries, the number of lanes in each direction varies from three to six lanes.

The concept for the Project was conceived several years ago and has been incorporated into a number of regional transportation studies and reports since 1996-97. (14 AR 4640-4673; 23 AR 8638; 11 AR 3716-3724.)

In June 2005, a Notice of Preparation of a Draft EIR for the Project was filed with the California Office of Planning and Research (State Clearing House). (21 AR 8078-8086.)

On December 13, 2006, Caltrans released the Draft EIR for a 60-day public review and comment period. (2 AR 508-775.) The Draft EIR identified two "build" alternatives (Alternatives 10d-1 and 10d-3) and a "No Build" alternative. (2 AR 513-514.) Alternative 10d-1 provides for the construction of HOV lanes from Sunrise Boulevard to the Oak Park interchange in downtown Sacramento. Alternative 10d-3, which is the approved Project, provides for the construction of the HOV lanes from Sunrise Boulevard to Watt Avenue. The No Build Alternative provides no improvements to Highway 50. The Draft EIR also identifies and discusses various other alternatives that were initially considered but then eliminated for various reasons. (2 AR 526-535.) Petitioners and others provided comments on the Draft EIR. (1 AR 339

Date: 07/15/2008 MINUTE ORDER Page: 1
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

through 2 AR 472.)

In June 2007, Caltrans issued the Final EIR. The Final EIR includes Caltrans' responses to the comments on the Draft EIR. (2 AR 473-507.) The Final EIR concludes that the Project will not result in any significant environmental impacts after mitigation. (1 AR 9-13; 4 AR 1419.)

On June 21, 2007, Caltrans certified the Final EIR and approved the Project. Caltrans adopted findings that the Project will not have a significant effect on the environment. (4 AR 1419; 1 AR 1.)

Caltrans filed a Notice of Determination under Public Resources Code § 21152 with the State Clearing House on June 25, 2007, commencing CEQA's 30-day period of limitations. (1 AR 1.) On the final day of that period, Petitioners filed the instant petition for writ of mandate, alleging that Caltrans violated CEQA.

Discussion

In determining whether an administrative body failed to comply with CEQA, the Court considers whether there was a prejudicial abuse of discretion. (Western States Petroleum Assn. v. Superior Court (1995) 9 Cal.4th 559, 568; Pub. Res. Code § 21168.5.) Abuse of discretion is established if the agency has not proceeded in a manner required by law or if the determination or decision is not supported by substantial evidence. (Citizens of Goleta Valley v. Board of Supervisors (1990) 52 Cal.3d 553, 564.)

Under the substantial evidence test, the court does not decide whether the agency's determinations were correct, but only whether they are supported by substantial evidence in the record. (Id.; see also Association of Irritated Residents v. County of Madera (2004) 107 Cal.App.4th 1383, 1391.)

Substantial evidence is defined as "enough relevant information and reasonable inferences from this information that a fair argument can be made to support a conclusion, even though other conclusions might also be reached." (Cal. Code Regs., tit.14, § 15384.) Substantial evidence includes facts, reasonable assumptions predicated upon facts, and expert opinion supported by facts. (Id.) Substantial evidence does not include "[a]rgument, speculation, unsubstantiated opinion or narrative, evidence which is clearly erroneous or inaccurate, or evidence of social or economic impacts which do not contribute to or are not caused by physical impacts on the environment . . . ." (Id.)

In applying the substantial evidence standard, the reviewing court does not reconsider or reweigh the evidence before the agency. The court must indulge all reasonable inferences from the evidence that would support the agency's determinations and resolve all conflicts in the evidence in favor of the agency's decision. (Western States Petroleum, supra, at p.571 [finding the power of the court begins and ends with a determination as to whether there is any substantial evidence, contradicted or uncontradicted, which will support the finding]; Laurel Heights Improvement Ass'n v. Regents of University of California (1988) 47 Cal.3d 376, 393.) A court should not set aside an agency's conclusion merely because an opposite conclusion would be equally or more reasonable. (Laurel Heights, supra, at p.393.)

In addition to reviewing whether an agency's factual determinations are supported by substantial evidence, a court may rule that an agency has prejudicially abused its discretion by failing to proceed in the manner required by law. (Pub. Res. Code §§ 21005, 21168, 21168.5; see also Rural Landowners Assn. v. City Council (1983) 143 Cal.App.3d 1013, 1022.) While an agency's factual determinations are subject to deferential substantial evidence review, questions of interpretation or application of the requirements of CEQA are matters of law, and are reviewed de novo. (Save Our Peninsula Committee v. Monterey County Bd. of Supervisors (2001) 87 Cal.App.4th 99, 119.) Thus, a reviewing court must adjust its review to the nature of the alleged defect, depending on whether the claim is predominantly a dispute over proper procedure or a dispute over the facts. (Vineyard Area Citizens for Responsible Growth, Inc. v. City of Rancho Cordova (2007) 40 Cal.4th 412, 435.)

An agency fails to proceed in the manner required by law if its analysis is based on an erroneous interpretation of CEQA's requirements or if it has failed to comply with the standards in CEQA for an adequate EIR.

When reviewing the adequacy of an EIR, a court does not pass upon the correctness of the EIR's environmental conclusions, but upon its sufficiency as an informational document. (Laurel Heights

Date: 07/15/2008 MINUTE ORDER Page: 2
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA DEPT OF TRANSPORT. ET AL Case No: 07CS00967

Improvement Ass'n v. Regents of University of California (1988) 47 Cal.3d 376, 392.) An EIR must include detail sufficient to enable those who did not participate in its preparation to understand and to consider meaningfully the issues raised by the proposed project. (Association of Irritated Residents v. County of Madera (2004) 107 Cal.App.4th 1383, 1390.) Failure to disclose relevant information in an environmental impact report (EIR) may constitute a prejudicial abuse of discretion regardless of whether a different outcome would have resulted if the agency had disclosed the information. (Laurel Heights, supra, at p.392; Kings County Farm Bureau v. City of Hanford (1990) 221 Cal.App.3d 692, 711-712; see also Association of Irritated Residents, supra, at p.1391 [existence of substantial evidence supporting agency's ultimate decision on a disputed issue is not relevant when assessing violation of the information disclosure provisions of CEQA].)

However, the absence of information in an EIR is not per se a prejudicial abuse of discretion. (Pub. Res. Code § 21005; Al Larson Boat Shop, Inc. v. Bd. of Harbor Commissioners (1993) 18 Cal.App.4th 729, 748; Association of Irritated Residents, supra, at pp.1391-92.) In reviewing the adequacy of an EIR, courts do not look for technical perfection, but for "adequacy, completeness, and a good faith effort at full disclosure." (Cal. Code Regs., tit.14, § 15151; Sequoyah Hills Homeowners Ass'n v. City of Oakland (1993) 23 Cal.App.4th 704, 712; Association of Irritated Residents, supra, at pp.1390-1391; see also Al Larson Boat Shop, supra, at p.748 [standard is "rule of reason"].) The sufficiency of an EIR is determined according to what is reasonably feasible. (Id.) The EIR need not be perfect so long as it provides agencies with sufficient information to enable them to make a decision that intelligently takes account of the environmental consequences of the proposed project. (San Francisco Ecology Center v. City and County of San Francisco (1975) 48 Cal.App.3d 584, 594.) A prejudicial abuse of discretion occurs only if the failure to include relevant information precludes informed decision making and informed public participation, thereby thwarting the statutory goals of the EIR process. (County of Amador v. El Dorado County Water Agency (1999) 76 Cal.App.4th 931, 946; Al Larson Boat Shop, supra, at p.748.)

Although the Legislature intended CEQA to be interpreted in such manner as to afford the fullest possible protection to the environment within the reasonable scope of the statutory language, an EIR is presumed adequate and the plaintiff in a CEQA action has the burden of proving otherwise. (See Al Larson Boat Shop, supra, at p.740.)

Petitioners in this case raise a number of procedural and substantive challenges to Caltrans' EIR. The Court separately addresses each of these challenges below.

The Project's Operational Impacts on Air Quality

The first issue presented relates to whether the EIR adequately discloses and analyzes the Project's operational impacts on air quality. Petitioners claim the EIR is insufficient as an informational document because the EIR fails to adequately analyze the Project's operational impacts on emissions of NOx, PM10, and PM2.5.

The law is settled that an EIR is intended to be an informational document. The purpose of an EIR is to provide public agencies and the public with detailed information about the effects a proposed project is likely to have on the environment, identify alternatives to the project, and indicate the manner in which those significant effects can be mitigated or avoided. (Pub. Res. Code § 21002.1; see also Pub. Res. Code §§ 21002, 21061, 21100.) In this manner, the EIR is intended to act as an "environmental 'alarm bell,' [alerting] the public and its responsible officials to environmental changes before they have reached ecological points of no return." (County of Inyo v. Yorty (1973) 32 Cal.App.3d 795, 810; see also Laurel Heights Improvement Assn. v. Regents of University of California (1988) 47 Cal.3d 376, 392 [EIR intended to demonstrate to an apprehensive citizenry that the agency has, in fact, analyzed and considered the ecological implications of its action].)

CEQA requires the agency to focus the discussion in the EIR on those potential effects on the environment which the agency has determined are or may be significant. Lead agencies may limit discussion on other effects to a brief explanation as to why those effects were determined not to be significant and therefore not discussed in detail in the EIR. (Pub. Res. Code §§ 21002.1, 21100(c); Cal. Code Regs., tit. 14, § 15128.) Determining whether a project may have a significant effect on the environment, therefore, plays a critical role in the CEQA process. (Cal. Code Regs., tit. 14, § 15064.)

Date: 07/15/2008 MINUTE ORDER Page: 3
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA DEPT OF TRANSPORT. ET AL Case No: 07CS00967

CEQA defines significant effects to mean substantial, or potentially substantial, adverse changes in the environment, including the land, air, water, minerals, flora, fauna, noise, historic and cultural sites, and aesthetics. (Pub. Res. Code §§ 21060.5, 21068, 21100, 21151; Cal. Code Regs., tit. 14, §§ 15126.2, 15360, 15382.)

There is no "gold standard" for determining whether a given environmental impact is significant. (Protect the Historic Amador Waterways, supra, at p.1107.) A precise definition of significant effects is not possible because the significance of an activity varies according to a project's environmental setting. (Cal. Code Regs., tit. 14, § 15064.) The determination of whether a project may have a significant effect on the environment calls for judgment on the part of the public agency, based to the extent possible on scientific and factual data. (Id.)

In this case, Petitioners challenge the methodology and scope of analysis used by Caltrans to assess the Project's air quality impacts. Petitioners contend that Caltrans improperly relied exclusively on a federal Clean Air Act conformity analysis to evaluate whether there will be significant air quality impacts from the Project. Further, Petitioners contend there is no evidence or rationale supporting Caltrans' decision to limit the scope of its analysis in this manner. Petitioners claim that because Caltrans relied on federal Clean Air Act conformity as the sole threshold of significance, Caltrans failed to analyze and disclose critical information about the Project's impacts on emissions of PM10, PM2.5, and NOx, including what those impacts are and how much of the regional emissions budgets they constitute.

Caltrans admits that it relied exclusively on a federal Clean Air Act conformity approach to evaluate the Project's air quality impacts, but denies that its conformity-based approach violates CEQA. The initial question presented, therefore, is whether a federal Clean Air Act conformity approach is sufficient to meet the requirements of CEQA.

Before proceeding to address this issue, some background on the federal Clean Air Act is required.

The Clean Air Act establishes a joint state and federal program to control the nation's air pollution. The Act requires the EPA to establish national ambient air quality standards ("NAAQS"), which establish the maximum limits of pollutants allowed in the outside ambient air. (42 U.S.C. § 7409.) The EPA must designate areas that meet the standards ("attainment areas") and those that do not meet the standards ("non-attainment areas"). (42 U.S.C. § 7407.) The Sacramento region has been designated by the EPA as a "non-attainment" area for PM10 and O3, but as "attainment" for PM2.5.

Under the Clean Air Act, states implement, attain, and enforce the NAAQS through regional state implementation plans ("SIPs"). (42 U.S.C. §§ 7409, 7410.) Each SIP identifies the total allowable amount of emissions necessary to attain and maintain the NAAQS for each pollutant, and allocates the total allowable emissions between stationary, mobile, and other sources. (42 U.S.C. § 7410; 40 C.F.R. § 93.101.) Federally approved transportation projects located in non-attainment areas must conform to the SIP. (Id.)

The Clean Air Act also requires conformity findings for metropolitan transportation plans ("MTPs") and metropolitan transportation improvement programs ("MTIPs"). MTPs describe the policies and strategies for accommodating current and future travel demand in the region. An MTP typically includes all of the federally-sponsored and regionally-significant transportation projects planned for the region over a period of years, usually at least 20 years. An MTIP describes specific transportation projects that are consistent with the MTP. The regional planning organization – in this case, SACOG – is required to ensure that the MTPs and MTIPs conform to the mobile source emissions budgets established in the SIP. (42 U.S.C. § 7506.)

Here, Caltrans relied exclusively on the Project's conformity with federal Clean Air Act standards to evaluate whether the Project will have any significant air quality impacts. Petitioners argue that while a Clean Air Act conformity-based approach may be sufficient to analyze the Project's cumulative air quality impacts, it is not sufficient to discharge Caltrans' duty to analyze and disclose the Project's specific traffic-based emissions. The Court agrees.

While regulatory environmental standards can provide an appropriate benchmark for determining whether a particular impact is significant, compliance with environmental laws is not enough to support a finding of no significant impact under CEQA. (Californians for Alternatives to Toxics v. Department of

Date: 07/15/2008 MINUTE ORDER Page: 4
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA DEPT OF TRANSPORT. ET AL Case No: 07CS00967

Food and Agriculture (2005) 136 Cal.App.4th 1, 17.)

In Californians for Alternatives to Toxics, the Court of Appeal addressed the question whether the Department of Food and Agriculture (DFA) could forgo environmental analysis of the statewide use of pesticides for a disease control program by relying on the Department of Pesticide Regulation's (DPR's) certified regulatory program. In its EIR, DFA did not independently evaluate the environmental impacts of the project's use of pesticides. Instead, DFA determined that compliance with DPR's existing regulatory scheme was adequate to ensure the project would not result in any significant adverse environmental impacts. Specifically, DFA reasoned that because all pesticide applications must be in compliance with DPR's existing regulatory program, and because the DPR pesticide program was approved as meeting the requirements of CEQA with respect to the use of pesticides, the use of pesticides by DFA according to approved label directions also must comply with CEQA. (Id. at p. 17.)

The Court of Appeal held that DFA's reliance on DPR's regulatory program was not sufficient to comply with CEQA. As the lead agency, DFA was responsible for presenting the facts, data, and analysis necessary to meaningfully assess the environmental impacts of its project. (Id. at p.13; see also Whitman v. Board of Supervisors (1979) 88 Cal.App.3d 397, 411 [requiring specificity and detail in EIRs since a conclusory statement affords no basis for a comparison of the problems involved with the proposed project and the difficulties involved in the alternatives]; Cal. Code Regs., tit. 14, § 15147.) The Court held that DFA fell short of its duty under CEQA by deferring to DPR's regulatory scheme as a substitute for performing its own evaluation of the environmental impacts of its program. (Californians for Alternatives to Toxics, supra, at pp.16-17.) According to the Court, DFA could not rely solely on compliance with an existing regulatory program to conclude that its proposed project would not result in significant adverse impacts. (Id. at p. 17.) "Compliance with the law is not enough to support a finding of no significant impact under the CEQA." (Id.)

The Court in Californians for Alternatives to Toxics acknowledged that DFA's duty to analyze the effects of pesticide use must take account of DPR's existing regulatory scheme, but the Court stated that this does not require DFA to duplicate the work of DPR. The Court suggested DFA could satisfy its duty under CEQA by considering DPR's existing data in the context of the specific project proposed by DFA. (Id. at pp. 16, 18.) DFA's EIR, however, contained only conclusory statements, unsupported by any data or environmental analysis. Thus, the Court ruled that DFA's EIR was inadequate. (Id. at pp. 13, 17.)

As a general rule, an EIR "must contain facts and analysis, not just the bare conclusions of a public agency." (Kings County Farm Bureau v. City of Hanford (1990) 221 Cal.App.3d 711, 736, quoting Santiago County Water Dist. v. County of Orange (1981) 118 Cal.App.3d 818, 831; Laurel Heights Improvement Assn. v. Regents of the Univ. of Cal. (1988) 47 Cal.3d 376, 404 [same].) While an agency's opinion concerning matters within its expertise may be of value, the public and decision-makers, for whom the EIR is prepared, should also have before them the basis for that opinion so as to enable them to make an independent, reasoned judgment. (Kings County Farm Bureau, supra, at p. 736; Californians for Alternatives to Toxics, supra, at p. 13 ["EIR should set forth specific data, as needed to meaningfully assess whether the proposed activities would result in significant impacts"]; Citizens to Preserve Ojai v. County of Ventura (1985) 176 Cal.App.3d 421, 429 [EIR should be prepared with a sufficient degree of analysis to make a decision which intelligently takes account of environmental consequences]; see also Citizens Assoc. for Sensible Dev. of Bishop Area v. County of Inyo (1985) 172 Cal.App.3d 151, 171 [initial study must disclose the data or evidence upon which the person conducting the study relied].)

Caltrans' EIR fell short of these standards. In its EIR, Caltrans determined that because the Project is included in the MTP and MTIP and will not violate any federal "hot spot" requirements, the Project is in conformity with the SIP. The EIR assumes that conformity with the SIP is sufficient to ensure the Project's emissions of PM10, PM2.5, and O3 will conform to regional air quality standards and, therefore, be less than significant. (1 AR 151-157.) The EIR does not, however, disclose or analyze the specific traffic-based emissions that would be generated by the Project. Nor does the EIR disclose or attach the MTP/MTIP, the SIP, or the air quality data and model used by SACOG to determine the MTP/MTIP's conformity with the SIP. Rather, similar to the DFA in Californians for Alternatives to Toxics, Caltrans relied on compliance with the federal Clean Air Act regulatory scheme in lieu of performing its own independent analysis of the specific environmental consequences of its Project. As discussed above, this is not sufficient under CEQA. Compliance with environmental laws alone is not adequate to support a finding of no significant impact under CEQA.

Date: 07/15/2008 MINUTE ORDER Page: 5
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA DEPT OF TRANSPORT. ET AL Case No: 07CS00967

Further, the record does not contain any evidence or analysis showing that a comprehensive analysis of the Project's actual traffic-based emissions would be infeasible or speculative. (See, e.g., 2 AR 486, 489, 503.)

As a post hoc rationalization for its failure to analyze the specific traffic-based emissions generated by the Project, Caltrans argues that a project-specific analysis of the Project's air quality impacts is unnecessary because (1) a federal Clean Air Act conformity analysis is functionally equivalent to CEQA's air quality requirements; and (2) HOV lanes are a federally recognized transportation control measure. Aside from the fact that Caltrans did not rely on these arguments in limiting the scope of its EIR, both of these arguments miss the mark.

Caltrans has not cited any authority to show that compliance with the Clean Air Act conformity analysis excuses compliance with CEQA. CEQA, unlike NEPA, does not exempt "functional equivalent" environmental schemes from its requirements. Insofar as CEQA may provide an exemption for agencies with functionally equivalent environmental responsibilities, it is only under the express statutory provision for "certified regulatory programs" set forth in Public Resources Code § 21080.5. (Mountain Lion Foundation v. Fish & Game Com. (1997) 16 Cal.4th 105, 121; City of Coronado v. California Coastal Zone Conservation Com. (1977) 69 Cal.App.3d 570, 582; see also Pub. Res. Code § 21080.5.) Here, nothing in CEQA suggests that a federal Clean Air Act conformity determination may be submitted in lieu of an EIR pursuant to the exemption in Public Resources Code § 21080.5.

Caltrans' second argument is also flawed. In essence, Caltrans argues that because the intended purpose of HOV lanes is to encourage carpooling, it is reasonable to assume the Project will reduce congestion, increase travel speeds, and decrease overall emissions. However, even if there is substantial evidence to support a determination that carpool lanes encourage carpooling, Caltrans has not cited any substantial evidence to support its assertion that encouraging carpooling means overall vehicle miles traveled and/or vehicle emissions will decrease or remain the same. Indeed, Caltrans admits that its EIR did not attempt to analyze (quantitatively or qualitatively) the Project's impacts on overall VMT, and, as discussed above, Caltrans did not independently evaluate the Project's specific traffic-based emissions. In contrast, there is evidence in the record suggesting that building HOV lanes can increase vehicle miles traveled and related emissions. (See discussion, infra.) In any event, as Petitioners contend, the EIR's failure to consider this issue – the potential of the Project to induce additional vehicle travel (i.e., new trips or longer trips) – is one of the primary reasons that the EIR is inadequate as an informational document.

Thus, Caltrans abused its discretion by relying on the Project's (purported) conformity with the SIP as a substitute for performing and presenting its own evaluation of the Project's environmental impacts. To be sufficient, the EIR must disclose and analyze the Project's specific traffic-based emissions.

In addition to failing to analyze and disclose the Project's specific traffic-based emission impacts, Caltrans also abused its discretion by relying on conformity with federal regulatory standards to foreclose consideration of potentially significant environmental impacts.

California courts have held that an agency cannot rely on established regulatory standards to foreclose consideration of substantial evidence that the project might have a significant environmental effect. (Protect the Historic Amador Waterways v. Amador Water Agency (2004) 116 Cal.App.4th 1099, 1109.) In preparing an EIR, an agency may use established regulatory standards as a measure of whether a certain environmental effect normally will be considered significant, but the agency cannot use the fact a particular environmental effect meets a threshold of significance as an automatic determinant that the effect is not significant. The agency must consider and resolve any substantial evidence of a fair argument that a certain environmental effect may be significant notwithstanding that the effect complies with established regulatory standards. (Protect the Historic Amador Waterways, supra, at p.1109; see also Cal. Code Regs., tit. 14, § 15064(i)(3).)

The Court acknowledges the fair argument standard normally would be limited to the issue of whether an EIR must be prepared. But courts in California have held that the fair argument standard also is properly applied when an agency has assessed the significance of impacts by relying on established regulatory standards. (Protect the Historic Amador Waterways, supra, at p.1109; Communities for a Better Environment, supra, at pp.113-114.) Thus, if the record contains substantial evidence to support a

Date: 07/15/2008 MINUTE ORDER Page: 6
Dept: 29 Calendar No.:

GL14 Continued

fair argument that the Project may have significant impacts on emissions of PM10, PM2.5, or O3, notwithstanding the Project's compliance with the federal Clean Air Act standards for those pollutants, case law holds that CEQA requires Caltrans to consider and discuss whether those possible significant environmental impacts will, in fact, be significant.

It is a question of law whether substantial evidence of a fair argument exists. (Pocket Protectors v. City of Sacramento (2004) 124 Cal.App.4th 903, 928.)

Substantial evidence to support a fair argument means "enough relevant information and reasonable inferences from this information that a fair argument can be made to support a conclusion, even though other conclusions might also be reached." (Cal. Code Regs., tit.14, § 15384; Pocket Protectors, supra, at p.927.) To raise a fair argument, it is not necessary to bring forth credentialed experts to offer scientifically irrefutable, site-specific information foretelling certain environmental harm. (Friends of the Old Trees v. Dep't of Forestry & Fire Prot. (1997) 52 Cal.App.4th 1383, 1402.) The evidence supporting a fair argument need not be overwhelming, overpowering, or even uncontradicted. (Id.)

Furthermore, because CEQA places the burden of investigation on the government rather than the public, an agency cannot hide behind its own failure to gather relevant data to defeat a fair argument. (Sundstrom v. County of Mendocino (1988) 202 Cal.App.3d 296, 311; Gentry v. City of Murrieta (1995) 36 Cal.App.4th 1359, 1379; City of Redlands v. County of San Bernardino (2002) 96 Cal.App.4th 398, 408.) The lack of study enlarges the scope of the fair argument by lending plausibility to a wider range of inferences. (Gentry, supra, at p.1379.)

The administrative record in this case contains substantial evidence to support a fair argument that the Project may cause a significant increase in traffic-based emissions notwithstanding the Project's compliance with the federal Clean Air Act conformity standards. Specifically, the administrative record contains substantial evidence of a fair argument that increasing the capacity of the highway may generate additional vehicle travel by inducing additional demand for vehicle travel (e.g., shifts from other transport modes, longer trips, new vehicle trips). (See, e.g., 23 AR 8586 [unintended effects of adding HOV lane may include induced trips]; 24 AR 8960, 8963 [noting statistically significant relationship between adding lane miles and VMT]; 2 AR 426, 428-430 [citing research discussing induced demand from expansion of roadway capacity]; 11 AR 3609 [discussing findings of model showing HOV lanes increase travel and emissions]; 11 AR 3683, 3692 [study discussing high occupancy vehicle lanes in the Sacramento region and noting that HOV lanes may increase VMT and emissions compared to no-build scenario].)

There also is substantial evidence of a fair argument that additional traffic generated by the Project may have a significant environmental impact on emissions of NOx, PM10, and PM2.5. There is substantial evidence, for example, that the Project may exceed SMAQMD's threshold of significance for NOx and cause non-attainment of the state standards for PM2.5 and PM10. (See 2 AR 463 [commenting that project may exceed SMAQMD's thresholds of significance for ROG and NOx]; 2 AR 398-399 [commenting that levels of PM10 measured at Branch Center Road station annually violate state ambient air quality standards and that the PM2.5 monitoring station closest to the Project regularly measures pollutant concentrations in excess of state standards]; 9 AR 3180-3181 [traffic report showing increase in freeway vehicle throughput relative to no build scenario].)

However, Caltrans did not consider or discuss the potential environmental impacts of induced demand in the EIR. The EIR discusses the Project's potential growth-inducing impacts on population and economic growth and land use patterns, and discusses the Project's potential to generate additional highway travel during peak periods by inducing shifts in routes or time of travel, but the EIR does not consider the potential for additional highway travel as a result of "induced demand." (2 AR 89-92, 475-477, 485-486, 490, 494, 498; 9 AR 3170.) The EIR expressly assumes, without support, that any additional highway traffic will consist of time of day or route shifts and will not increase overall VMT. (Id.) It is noteworthy that the administrative record includes an emissions study that accounts for induced demand, but the study was not analyzed in the EIR, was limited to a 5-year period, and expressly states that a "more expanded analysis is needed" to adequately compare the long-term emissions benefits/disadvantages of HOV lanes relative to a no-build scenario. (24 AR 8960; see Calif. Oak Found. v. City of Santa Clarita (2005) 133 Cal.App.4th 1219, 1239 [information scattered in EIR or buried in appendix is not substitute for good faith reasoned analysis].)

GL14 Continued

Caltrans argues that increases in VMT do not necessarily result in higher overall emissions, since emissions are a function of speed as well as VMT. (Opposition Brief, pp.9, 10.) However, there is substantial evidence in the record that emissions vary with VMT, and Caltrans did not perform a specific analysis of the Project's impacts on overall emissions. Thus, at best, Caltrans can argue that even if the Project increases overall VMT, it nevertheless might reduce overall emissions. But it is the failure to disclose and analyze these potentially significant impacts that renders the EIR inadequate from an informational standpoint.

Thus, the Court concludes that Caltrans applied the federal Clean Air Act conformity standards in a way that foreclosed the consideration of substantial evidence tending to show the Project may have significant air quality impacts notwithstanding its compliance with the federal conformity standards. Caltrans was not compelled to find that the Project will have a significant impact on emissions of NOx, PM10, and PM2.5, but Caltrans should have analyzed and discussed whether the Project may have a significant impact on such emissions notwithstanding the Project's compliance with the federal Clean Air Act conformity standards.

For all of these reasons, the Court concludes that the EIR is inadequate and incomplete as an informational document in respect to the Project's operational impacts on emissions of NOx, PM10, and PM2.5.

The Determination that the Project Will Not Increase Vehicle Miles Traveled

Petitioners argue that Caltrans' analysis regarding the Project's potentially significant environmental impacts relies upon a determination that the Project will not result in an increase in VMT (vehicle miles traveled). Petitioners allege that this conclusion is not supported by substantial evidence in the record. Rather, Petitioners claim, the administrative record shows that construction of HOV lanes induces additional demand, which will result in an increase in overall VMT. (See Petitioners' Reply Brief, p.13 [citing 2 AR 428; 9 AR 3154, 3180; 10 AR 3589-3607; 11 AR 3609, 3683, 3685, 3689, 3692; 24 AR 8960, 9194].)

Caltrans denies that its EIR was based on any analysis, or any determination, of the Project's impact on VMT. (See Opposition Brief, pp.18, 20.) This is correct. The record shows that Caltrans made no effort to disclose or analyze the impact that the Project may have on overall VMT in the Highway 50 corridor.

Since Caltrans never determined the Project's impact on overall VMT, it is unnecessary for the Court to decide whether that determination is supported by substantial evidence. However, to the extent Caltrans assumed for purposes of its EIR that the Project would have no impact on overall VMT, the Court finds that assumption is not supported by substantial evidence, for the reasons discussed above.

The Project's Potentially Significant Impacts on Local Roads and Parking

Petitioners allege the EIR fails to adequately disclose and analyze the Project's impacts on the volume, distribution, and flow of traffic on local roadways, and on the demand for parking in downtown Sacramento.

The EIR states that parallel routes and local street connections at freeway off-ramps were analyzed up to the first intersection, but Caltrans concedes that the EIR does not quantify these impacts. (See Respondent's Supplemental Brief, p. 7; see also 2 AR 497, 500.) Caltrans contends that the EIR nevertheless adequately discussed the Project's impacts on local roadways and parking since there is no reason to believe that the Project would have a potentially significant adverse impact on local roads or parking.

Although the EIR's failure to disclose the analysis of the Project's impacts on local street connections renders the EIR less than perfect, the Court is not persuaded that it precluded informed decision making and informed public participation. Even if the Project will increase the number of vehicles exiting the highway and entering local roads, the Final EIR adequately discusses this issue. (See 2 AR 485 [parallel routes were analyzed as were all local street connections at off-ramp termini up to first intersection], 490 [traffic study does not suggest commuters would be likely to divert to local streets as result of project], 491 [not practical for Caltrans to model the entire local street system], 496 [project would not alter traffic patterns in central Sacramento, and traffic signal connections would control the flow rate of traffic onto

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

city streets], 497 [induced parking demand is not anticipated], 502 [Caltrans lacks authority to impose or enforce parking requirements].)

The EIR's discussion of the Project's impacts on local roads and parking is adequate.

The Project's Growth Inducing Impacts

Petitioners allege the EIR fails to adequately analyze the Project's growth inducing impacts.

Under CEQA, a project has growth inducing impacts if it will (1) foster economic or population growth or additional housing; (2) remove obstacles to growth; or (3) facilitate other activities that cause significant environmental effects. (Cal. Code Regs., tit.14, § 15126.2(d); see also City of Antioch v. City Council (1986) 187 Cal.App.3d 1325, 1335-1338; Stanislaus Audobon Society, Inc. v. County of Stanislaus (1995) 33 Cal.App.4th 144, 152-160; Napa Citizens for Honest Gov't v. Board of Supervisors (2001) 91 Cal.App.4th 342, 367-371.)

In discussing the Project's growth inducing impacts, a distinction must be made between the concept of "induced demand" and Petitioners' use of the phrase "growth inducing impacts." "Induced demand" is the concept that the increase in the capacity of the highway may generate additional vehicle travel by inducing additional demand for vehicle travel (e.g., shifts from other transport modes, longer trips, new vehicle trips). In contrast, when Petitioners refer to the Project's "growth inducing impacts," Petitioners are referring to the ways in which the proposed Project could directly or indirectly foster economic, population, or housing growth in the surrounding environment, and the related effects this might have on traffic and the environment. (Cal. Code Regs., tit. 14, §§ 15126.2(d), 15358(a)(2).) "Induced demand" is broader than a project's "growth inducing impacts" in that a highway project's "growth inducing impacts" may contribute to "induced demand," but "induced demand" also may occur even if the project will not have any "growth inducing impacts." In this section, the Court is addressing only Petitioners' assertion that the EIR did not adequately disclose and analyze the Project's "growth inducing impacts."

In this context, Petitioners allege the EIR failed to adequately disclose and analyze the Project's growth inducing impacts because the EIR states that population and employment growth occurs independent of the Project and will accelerate in the future with or without the addition of HOV lanes on U.S. Highway 50. Petitioners contend that the EIR is trivializing the Project's growth inducing impacts. (See Kings County Farm Bureau v. City of Hanford (1990) 221 Cal.App.3d 711, 718 [project's impact may be significant even though project contributes only a small amount to an existing problem].) Petitioners allege there is substantial evidence in the record to show that increases to highway capacity facilitate and accommodate regional growth. Thus, Petitioners contend, the EIR's analysis must use separate growth projections for the build and no-build scenarios to adequately account for the growth-inducing impacts of the Project.

Petitioners claim lacks merit. The EIR did not, as Petitioners suggest, find that growth in the Sacramento region occurs independent of construction of new highway capacity. To the contrary, the EIR expressly finds that regional traffic projects may have an impact on regional growth or land use. However, given existing and projected development in the area, and given the data showing that the Project is not expected to eliminate peak period traffic congestion or significantly improve the highway's peak period level of service,
Caltrans determined that the proposed Project would not add sufficient additional highway capacity to significantly affect growth patterns in the U.S. 50 corridor. (1 AR 89-92, 201-202; 2 AR 475, 485, 492, 494, 498.) This determination is supported by substantial evidence in the record. (Id.; 9 AR 3167-3168.) Accordingly, the Court concludes that the EIR adequately analyzes the Project's growth inducing impacts.

The Project's Contribution to Global Warming

Petitioners argue that the EIR also violates CEQA because it fails to analyze the Project's contributions to global warming. In light of the Governor's Executive Order (S-3-05) on global warming, and the legislative requirement that greenhouse gas (GHG) emissions be reduced to 1990 levels by the year 2020, Petitioners contend CEQA requires agencies to analyze a project's impacts on global warming. In order to properly analyze a project's global warming impacts, Petitioners assert, an EIR should (i) provide a regulatory and scientific background on global warming; (ii) assess the project's contribution to

Date: 07/15/2008 MINUTE ORDER Page: 9
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

GHG emissions and the potential impact of those GHG emissions on global warming; (iii) assess the effect of climate change on the project and its impacts; and (iv) make a significance determination.

Caltrans argues that the field of global warming is still in its "infancy." Caltrans notes that the California Global Warming Solution Act of 2006, codified at Health & Safety Code § 38500 et seq., was the nation's first mandatory cap on GHG emissions. Caltrans also notes that evaluation of a project's impact on global warming traditionally has not been demanded under CEQA. Although the Legislature has directed the Office of Planning and Research to develop guidelines for addressing GHG emissions in CEQA, those guidelines do not yet exist and are not required to be finalized until January 1, 2010. Consequently, Caltrans argues there is no workable framework for presenting the GHG analysis that Petitioners demand. According to Caltrans, this means any analysis of the Project's impact on global warming is too speculative for evaluation under CEQA.

Caltrans also argues that this Project's failure to analyze the effects of GHG emissions is not subject to legal challenge pursuant to Public Resources Code § 21097.

The Court agrees with Petitioners that the exemption in Public Resources Code § 21097 does not apply to this Project.

Although § 21097 exempts certain transportation projects – including, potentially, this one – from claims based on a failure to adequately analyze the effects of GHG emissions, that statute applies retroactively only to EIRs that have not become "final." The dispute in this case centers on the meaning of the term "final."

Caltrans contends – not unreasonably – that if the term "retroactively" is to have any meaning, then § 21097 must apply to EIRs certified before adoption of the legislation. If the intent merely was to make § 21097 retroactive to uncertified EIRs, Caltrans argues, then subdivision (c) was superfluous because § 21097 already would have applied to conduct occurring after the effective date of the statute, including certification of an EIR. (See Fairbank v. City of Mill Valley (1999) 75 Cal.App.4th 1243, 1257 [propriety of agency action under CEQA is determined on the date on which the document is presented for public review].) Because the general purpose of the statute was to insulate certain state transportation projects from causes of action based on a failure to adequately analyze the effects of GHG emissions, Caltrans claims the intent of subdivision (c) was to make the protections of § 21097 retroactive to all EIRs, including previously certified EIRs, provided the cause of action itself had not become "final."

In response, Petitioners argue that the statute plainly and unambiguously provides it "shall apply retroactively to an environmental impact report . . . that has not become final." Thus, Petitioners claim, retroactivity depends on the finality of the EIR, not the finality of the cause of action. Petitioners contend that the Legislature used the term "retroactively" to clarify that § 21097 would apply to steps in the CEQA process already undertaken on the effective date of the legislation, provided the EIR or other document had not yet become "final." (See Cal. Code Regs., tit. 14, § 15007(b).)

Although both arguments have some appeal, the Court is persuaded that Petitioners have the better argument. It is the Court's opinion that the Legislature used the word "final" in the same sense it is used in Code of Civil Procedure § 1094.5. (See Civ. Proc. Code § 1094.5 [providing for inquiry into the validity of any final administrative order or decision].) The Legislature did not intend § 21097(a) to apply to a Final EIR certified before the effective date of the legislation.

Section 21097 was signed into law on August 24, 2007, and became effective on January 1, 2008. Caltrans certified its Final EIR on June 21, 2007, months before the effective date of the legislation. Thus, this project does not qualify for the exemption in Public Resources Code § 21097.

The Court next considers whether the EIR provided adequate information about the Project's contributions to global warming, and concludes it did not.

The EIR recognizes the concern that GHG emissions raise for climate change, but concludes that because there is no accepted federal, state, or regional methodology for GHG emission and climate change impact analysis, analyzing the impacts associated with an increase in GHG emissions at the project level is not currently possible. (1 AR 159.)

Date: 07/15/2008 MINUTE ORDER Page: 10
Dept: 29 Calendar No.:

GL14 Continued

However, as Petitioners point out, nothing in the administrative record supports Caltrans' conclusion that it is not possible to quantify the Project's GHG emissions, at which point, Caltrans could make its own evaluation of their significance. While CEQA does not require an agency to foresee the unforeseeable, CEQA does require an agency to use its best efforts to find out and disclose all that it reasonably can. (Cal. Code Regs., tit. 14, § 15144.) Only after thorough investigation may an agency find that a particular impact is too speculative for evaluation and terminate its discussion of the impact. (Cal. Code Regs., tit. 14, § 15145 [emphasis added]; see Berkeley Keep Jets Over the Bay Committee v. Board of Commissioners (2001) 91 Cal.App.4th 1344, 1370-1371 [fact that a single methodology does not currently exist does not excuse evaluation].) Here, there is no evidence in the record that Caltrans performed any investigation whatsoever. This fell short of Caltrans' duty to make a good faith effort to investigate and disclose all that it reasonably can.

Caltrans must meaningfully attempt to quantify the Project's potential impacts on GHG emissions and determine their significance, or at the very least explain what steps it has taken that show such impacts are too speculative for evaluation.

The Project's Construction-Related Impacts on Air Quality

Petitioners also allege that the EIR violates CEQA because it fails to quantify and adequately analyze the Project's construction-related impacts on air quality.

Caltrans concedes that construction equipment will generate emissions while the Project is being built. Nevertheless, Caltrans argues that the EIR is adequate in terms of informing the public about these environmental impacts. According to Caltrans, the EIR adequately advises the public that the Project may result in the generation of short-term construction-related emissions, and that such emissions will be controlled and rendered less than significant by requiring compliance with best management practices, Caltrans' Standard Specifications, and all pertinent rules, regulations, and ordinances of the SMAQMD. (See 1 AR 12, 157, 199; 2 AR 505.)

As described above, the sufficiency of the information contained in an EIR is reviewed in light of what is reasonably feasible. (Cal. Code Regs., tit. 14, § 15151; Rio Vista Farm Bureau Ctr. v. County of Solano (1992) 5 Cal.App.4th 351, 374-375.) "Feasible" means "capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, legal, social, and technological factors." (Cal. Code Regs., tit. 14, §§ 15147, 15364; see also Citizens to Pres. the Ojai v. County of Ventura (1985)176 Cal.App.3d 421, 429-430 [noting courts favor specificity and use of detail in EIRs].)

In this case, an evaluation of the Project's short-term construction-related emissions reasonably was feasible using SMAQMD's established methodology and thresholds of significance. (See 2 AR 463; 13 AR 4536.) Yet Caltrans made no effort to quantify this Project's construction-related air quality impacts or to analyze whether and to what extent the Project is or is not consistent with SMAQMD's threshold of significance. Nor does the EIR explain why an analysis of the Project's construction-related air quality impacts would be infeasible. (See, e.g., 2 AR 505; see also Ojai, supra, at p.430 [EIR failed to explain reliance on earlier analysis]; Berkeley Keep Jets Over the Bay Committee v. Board of Commissioners (2001) 91 Cal.App.4th 1344, 1368-1370 [EIR failed to support decision not to evaluate health risks with any meaningful analysis].) Accordingly, Caltrans' EIR failed to adequately disclose and consider the Project's potentially significant construction-related emissions.

The Description and Analysis of the Project's Community Enhancements

Petitioners allege Caltrans' EIR is inadequate because it does not provide a stable and accurate project description.

An accurate, stable, and finite project description is the sine qua non of an informative and legally sufficient EIR. (County of Inyo v. City of Los Angeles (1977) 71 Cal.App.3d 185, 193.) An adequate project description is necessary to ensure that CEQA's goals of providing information about a project's environmental impacts will not be rendered useless. An overly narrow description of a project could result in an agency overlooking a project's cumulative impact by focusing on the isolated parts of the whole. (Rio Vista Farm Bureau Ctr. v. County of Solano (1992) 5 Cal.App.4th 351, 370.) Thus, to further the objectives of CEQA, the term "project" is defined broadly to include the "whole of an action, which

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

has a potential for resulting in either a direct physical change in the environment, or a reasonably foreseeable indirect change in the environment." (Cal. Code Regs., tit. 14, § 15378(a).)

The description of a project in an EIR should be sufficient to provide public agencies and the public with detailed information about the effects the proposed project is likely to have on the environment. (Dry Creek Citizens Coalition v. County of Tulare (1999) 70 Cal.App.4th 20, 26.)

On the other hand, the project description in an EIR is not required to supply extensive detail beyond that needed for evaluation and review of the environmental impact of the project actually being proposed. (Cal. Code Regs., tit. 14, § 15124.) CEQA requires consideration only of the potential environmental effects of the proposed project, not some hypothetical project. (Rio Vista Farm Bureau Ctr. v. County of Solano (1992) 5 Cal.App.4th 351, 372.) No purpose would be served by requiring an EIR to speculate as to the environmental consequences of future activities that are unspecified or uncertain when the project is proposed. (Id. at pp.372-373.) Accordingly, the project description in an EIR should not include future activities if it is not possible to provide meaningful information about those activities at the time the project is proposed. (Id.)

Petitioners allege Caltrans' EIR does not provide a stable and accurate project description because it fails to adequately identify and describe the proposed "community enhancements."

The Draft EIR states that Caltrans is committed to provide funding for "community enhancements" proposed by the Citizens Advisory Committee and/or requested by affected local governments. (2 AR 513, 524, 535-536.) Although the CAC and local governments identified numerous potential community enhancements – both within and without Caltrans' right-of-way – the Draft EIR never identifies what enhancements will be included in the Project. Similarly, the Final EIR states that the community enhancements will include certain sound walls and landscaping, but it does not state that the community enhancements will be limited to soundwalls and landscaping. (1 AR 32-33.)

Caltrans concedes that the EIR does not identify and describe all the "community enhancements" that actually will be included in the Project. However, Caltrans contends this was reasonable and necessary because it was not possible to identify all of the community enhancements at the time the Project was proposed. According to Caltrans, the final list of community enhancements could not be determined until after the close of the environmental review process because each affected local jurisdiction has the discretion to decide how to spend its share of the community enhancement funds, and such decisions do not have to be made until funding is actually allocated to the local jurisdictions.

Notwithstanding the obvious uncertainty as to what community enhancements will be constructed as part of the Project, (1 AR 6), the Court agrees with Caltrans that the uncertainty does not arise from any attempt by Caltrans to improperly constrain its environmental review by improper segmenting. Rather, it arises from a good faith effort to be inclusive – or perhaps over-inclusive – in describing the "whole of the action" being approved. (See, e.g., Cal. Code Regs., tit. 14, § 15378(b)(4) [a project does not include creation of government funding mechanisms or fiscal activities which do not include any commitment to any specific project].)

Caltrans has made clear that if a local jurisdiction chooses to commit funding to a community enhancement that was not evaluated in the EIR, then that enhancement will be subject to full CEQA review. Caltrans maintains that no community enhancement will be constructed without full CEQA review. Thus, while the EIR's description of the project was not perfect, the description did not preclude informed decision making and informed public participation. (See, e.g., Dusek v. Redev. Agency of City of Anaheim (1985) 173 Cal.App.3rd 1029, 1040-1041 [discrepancy between project description and project approved does not violate CEQA where agency approves a narrower project than that described in EIR]; see also Laurel Heights Improvement Assn. v. Regents of the Univ. of Cal. (1988) 47 Cal.3d 376, 394 [upholding description that defined projects as "[moving] the School of Pharmacy basic science research units from the UCSF Parnassus campus to Laurel Heights"]; Nat'l Parks & Conservation Ass'n v. County of Riverside (1996) 42 Cal.App.4th 1505, 1520 [deferral of environmental assessment does not violate CEQA where an EIR cannot currently provide meaningful information about uncertain or unspecified future projects].)

In addition to challenging the description of the project, Petitioners allege that the EIR failed to adequately disclose and analyze the potential environmental impacts of the community enhancements.

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

For the reasons discussed above, the Court concludes that the EIR was not rendered inadequate for failing to discuss possible community enhancements that either were not reasonably foreseeable at the time the project was proposed or that will not have any significant effect on the project or its environmental impacts. (See Laurel Heights Improvement Assn., supra, at pp. 395-396.)

However, in respect to the prospective community enhancements that were identified by the CAC and affected local governments, the Court agrees with Petitioners. The Court could not locate any analysis or evaluation of the possible adverse environmental impacts of the identified community enhancements. (See Sacramento Old City Ass'n v. City Council (1991) 229 Cal.App.3d 1011, 1027 [if the inclusion of a mitigation measure would itself create new significant effects, these too, must be discussed].) This lack of analysis renders this portion of the EIR inadequate as an informational document.

The Geographic Scope of the EIR's Cumulative Impact Analysis

Petitioners allege the geographic scope of the EIR's cumulative impact analysis was unduly restricted to the Highway 50 corridor. Petitioners assert the geographic scope of the cumulative impact analysis should be regional (i.e., the area under the jurisdiction of the SMAQMD), rather than strictly limited to the Highway 50 corridor. (See Opening Brief, p. 19 [citing Citizens to Preserve the Ojai v. County of Ventura (1986) 176 Cal.App.3d 421, 431-432; Cal. Code Regs., tit.14, § 15130(b)(3)].)

When determining the geographic scope of the area affected by the cumulative impacts of a project, the court reviews whether the lead agency has provided a reasonable explanation for the geographic limitation used. (Cal. Code Regs. tit. 14, § 15130(b)(3).)

Caltrans maintains that the geographic scope of its cumulative impact analysis was reasonable under the circumstances. The Court agrees.

For analysis related to transportation impacts, the scope of Caltrans analysis encompassed the Highway 50 corridor, but also considered the impacts from development projects in a larger area encompassing Rancho Cordova, Folsom, downtown Sacramento, and the unincorporated areas of Sacramento County. (See 7 AR 2508-2532; 1AR 198; see also 1 AR 198-259.) For analysis related to air quality, the EIR's analysis was regional, encompassing the entire Sacramento Valley Air Basin. (1 AR 151, 199.) Caltrans has provided a reasonable explanation for the geographic scope of its cumulative impact analysis. Thus, the geographic scope of the EIR's cumulative impact analysis did not violate CEQA.

The EIR's Discussion of Project Alternatives

Petitioners allege that the EIR is inadequate because it fails to discuss a reasonable range of project alternatives.

CEQA does not require an EIR to consider every conceivable alternative to a project. CEQA only requires an EIR to describe a range of potentially feasible alternatives.

The range of alternatives required to be considered in an EIR is governed by a "rule of reason." (Cal. Code Regs., tit. 14, § 15126.6(f).) The EIR should include those alternatives that could feasibly accomplish most of the basic objectives of the project and could avoid or substantially lessen one or more significant effects. (Cal. Code Regs., tit. 14, § 15126.6(a), (c).)

There is no categorical legal imperative as to the scope of alternatives to be analyzed in an EIR; each case must be evaluated on its facts. However, the range of alternatives considered in an EIR must represent enough variation to allow informed decisionmaking and informed public participation. (Cal. Code Regs., tit. 14, § 15126.6(a); Preservation Action Council v. City of San Jose (2006) 141 Cal.App.4th 1336, 1351.)

An EIR is required to include an in-depth discussion of those alternatives identified as at least potentially feasible. (Preservation Action Council, supra, at pp.1350-1351; Citizens of Goleta Valley v. Bd. of Supervisors (1990) 52 Cal.3d 553, 569.) On the other hand, an EIR is not required to consider alternatives which are infeasible. (Id.) Thus, the lead agency must make an initial determination as to which alternatives are potentially feasible and merit in-depth consideration, and which do not. (Citizens of Goleta Valley, supra, at p.569.)

Date: 07/15/2008 MINUTE ORDER Page: 13
Dept: 29 Calendar No.:

GL14 Continued

Case Title: ENVIR COUNCIL OF SAC. ET AL VS. CA Case No: 07CS00967
DEPT OF TRANSPORT. ET AL

The Legislature has defined "feasible" for purposes of CEQA to mean "capable of being accomplished in a successful manner within a reasonable period of time, taking into account economic, environmental, social, and technological factors." (Pub. Res. Code § 21061.1; see also Cal. Code Regs., tit. 14, § 15364.) Among the factors that may be taken into account when assessing feasibility of alternatives are site suitability, economic viability, availability of infrastructure, general plan consistency, other plans or regulatory limitations, jurisdictional boundaries, and whether the proponent reasonably can acquire, control, or otherwise have access to the alternative site. (Cal. Code Regs., tit. 14, § 15126.6(f)(1); Citizens of Goleta Valley, supra, at pp.574-575.)

The EIR should briefly describe the rationale for selecting the potentially feasible alternatives considered in-depth in the EIR. (Cal. Code Regs., tit. 14, § 15126.6(c).) The EIR also should identify the alternatives that were rejected during the scoping process, and briefly explain the reasons underlying the agency's determination. (Id.) Evidence of infeasibility need not be found within the EIR itself. However, a finding of infeasibility must be supported by substantial evidence in the record. (Citizens of Goleta Valley, supra, at p. 569.)

Here, Petitioners acknowledge that Caltrans considered and rejected many alternatives during the scoping process. (See 1 AR 24-32.) Nevertheless, Petitioners allege that the EIR fails to discuss a reasonable range of alternatives because the EIR considered only two "build" alternatives – with little variation between them – and failed to consider a transit-only alternative. (1 AR 24-32.) The Court agrees.

The EIR did not include an in-depth discussion of the transit-only alternative because SACOG's HOV-US 50 Corridor Study suggested that both light rail extensions and HOV lanes were necessary to alleviate congestion in the corridor. (1 AR 30.) But even if this statement is accurate, it is not a proper basis to reject the transit-only alternative as infeasible. (Cal. Code Regs., tit.14, § 15126.6(b) ["the discussion of alternatives shall focus on alternatives . . . which are capable of avoiding or substantially lessening any significant effects of the project, even if these alternatives would impede to some degree the attainment of the project objectives, or would be more costly."])

The test is not whether the transit-only alternative is the best strategy to achieve the Project's objectives, but whether it is a reasonable alternative that could feasibly accomplish most of the basic objectives of the Project and avoid or substantially lessen one or more of the Project's significant effects. (Cal. Code Regs., tit.14, § 15126.6; Wildlife Alive v. Chickering (1976) 18 Cal.3d 190, 197 [one of EIR's major functions is to ensure that all reasonable alternatives are thoroughly assessed].)

In this case, the objectives of the Project are to improve mobility, provide an option for reliable peak period travel time, improve traffic operations by reducing congestion and travel time, use highway facilities as efficiently as possible, provide incentives for commuters to use carpools, vanpools, or buses during peak period travel, and identify projects and strategies to improve adjacent street system and thereby enhance neighborhood livability. (1 AR 20.) The transit-only alternative is a potentially feasible alternative that could accomplish most of the basic objectives of the Project, while potentially avoiding or substantially lessening one or more potentially significant effects. (2 AR 417, 432-433; 11 AR 3648.) Thus, the transit-only alternative is a reasonable alternative that merits discussion and comparison to the two build options discussed in the EIR.

Because the EIR included only two build alternatives, with little variation between them, Caltrans' failure to include an in-depth discussion of the transit-only alternative precluded informed decision-making and informed public participation and rendered the EIR's discussion of alternatives inadequate. (Laurel Heights Improvement Assn. v. Regents of University of California (1988) 47 Cal.3d 376, 403-404.)

Impermissible Segmentation of Environmental Review

Petitioners contend that Caltrans impermissibly segmented its environmental review because the EIR fails to analyze a foreseeable extension of HOV lanes on major highways throughout the Sacramento region.

Although Caltrans admits that SACOG has an HOV network in concept, Caltrans denies that this Project

Date: 07/15/2008 MINUTE ORDER Page: 14
Dept: 29 Calendar No.:

GL14 Continued

is part of a larger enterprise to construct a comprehensive network of HOV lanes throughout the Sacramento region.

As described above, an EIR must consider all future phases of a project as the "whole of the action" so that "environmental considerations [do] not become submerged by chopping a large project into many little ones . . . ." (Burbank-Glendale-Pasadena Airport Auth. v. Hensler (1991) 233 Cal. App. 3d 577, 592.) On the other hand, CEQA does not require a detailed environmental analysis of every future activity that conceivably may occur. Where future activities are unknown or uncertain, no purpose would be served by requiring an EIR to speculate about their environmental consequences. (Laurel Heights Improvement Ass'n v. Regents of University of California (1988) 47 Cal.3d 376, 395, 398-399.) Generally speaking, an EIR should be prepared as early as feasible to enable environmental considerations to influence project design yet late enough to provide meaningful and reliable information for environmental review. (Id. at p. 395.)

In Laurel Heights, the California Supreme Court considered the difficult question of when an EIR is required to analyze the environmental effects of future activities that may become part of the project. The Court held that an EIR must analyze the environmental effects of a future activity if (1) it is a reasonably foreseeable consequence of the initial project; and (2) the future expansion or action will be significant in that it will likely change the scope or nature of the initial project or its environmental effects. (Id. at p. 396; see also Cal. Code Regs., tit. 14, § 15165.) Future activities not currently proposed for approval, and not reasonably foreseeable, need not be analyzed in the EIR. (Nat'l Parks & Conservation Ass'n v. County of Riverside (1996) 42 Cal.App.4th 1505, 1520.)

In Del Mar Terrace Conservancy, Inc. v. City Council (1992) 10 Cal.App.4th 712, the Fourth Appellate District Court of Appeal upheld a trial court's use of a federal standard for evaluating the specific issue of whether a particular highway project is an impermissible segmentation of a larger roadway project. (Del Mar Terrace Conservancy, Inc. v. City Council (1992) 10 Cal.App.4th 712, 732-735, disapproved on other grounds by Western States Petroleum Assn. v. Superior Court (1995) 9 Cal.4th 559.) The federal standard uses the following criteria to evaluate whether a proposed highway segment may be reviewed separately: (1) is the highway segment located between logical terminal points; (2) is the segment of sufficient length to assure adequate consideration of alternatives; (3) does the segment have "independent utility;" (3) and (4) does the segment seem to serve important state and local needs, such as relieving particular traffic congestion? (Id. at pp. 732-733.) The Court also considered whether approval of the segment would irretrievably commit the agency to a definite course of action in regard to other highway segments. (Id. at p. 734.)

Applying the criteria in Laurel Heights and, more specifically, Del Mar Terrace, the Court concludes that Caltrans did not impermissibly segment its environmental review of this Project. The evidence in the record supports the determination that this Project is of substantial length, is located between logical terminal points, serves important state and local needs, and has independent utility. Further, approval of the project would not irretrievably commit Caltrans to construct any other HOV-related projects. The eventual possible construction of a comprehensive network of HOV lanes throughout the Sacramento region was not, at the time the EIR was prepared, a reasonably anticipated future project. (2 AR 480.)

The CEQA Guidelines provide that where a project is one of several similar projects of a public agency, but is not deemed part of a larger project, the agency may prepare one EIR for all projects, or one for each project, but shall in either case comment, in at least general terms, upon the cumulative effect. (Cal. Code Regs., tit. 14, § 15165; see also Del Mar Terrace, supra, at p. 735, 736-737.) The Court's review of the record shows that Caltrans' EIR met this standard. (See, e.g., 1 AR 79, 83, 198, 205.)

The CEQA Findings

Petitioners finally allege Caltrans' Findings violate CEQA because (i) Caltrans failed to adopt a mitigation monitoring plan; (ii) the Findings fail to specify the location and custodian of the record of proceedings; and (iii) the Findings are not supported by substantial evidence.

Caltrans contends that nothing in CEQA requires an agency to adopt a mitigation monitoring program as part of its Findings.

However, even if CEQA does not state how a mitigation monitoring plan may be adopted, CEQA clearly

GL14 Continued

such action as may be necessary to bring the Project into compliance with CEQA; and (iv) file a return in this Court within six months after the issuance of the writ specifying what Caltrans has done to comply with the writ.

Petitioners are directed to prepare a formal judgment incorporating this ruling by reference, and a peremptory writ of mandate; submit them to opposing counsel for approval as to form; and thereafter submit them to the Court for signature and entry of judgment in accordance with Rule of Court 3.1312. Petitioners shall be entitled to recover their costs upon appropriate application. The Court shall retain jurisdiction to determine compliance with the writ and any motion for an award of attorney fees.

GL14 Continued

Case No. 07CS00967
Name of Case: Environmental Council of Sacramento, et al. vs. CA Dept. of Transportation, et al.

CERTIFICATE OF SERVICE BY MAILING
(C.C.P. Sec. 1013a(4)

I, the undersigned deputy clerk of the Superior Court of California, County of Sacramento, do declare under penalty of perjury that I did this date place a copy of the above-entitled RULING AFTER HEARING a notice envelopes addressed to each of the parties or their counsel of record as stated below, with sufficient postage affixed thereto and deposited the same in the United States Post Office at Sacramento, California.

Donald B. Mooney
Attorney at Law
129 C Street. Suite 2
Davis, CA 95616

Martin Keck
Attorney for Department of Transportation
1120 N Street (MS-57)
P.O. Box 1438
Sacramento, CA 95812-1438

I, the undersigned Deputy Clerk, declare under penalty of perjury that the foregoing is true and correct.

Dated: 7/15/08

SUPERIOR COURT OF CALIFORNIA
COUNTY OF SACRAMENTO

By: L. YOUNG
Deputy Clerk

GL14 Continued

PROOF OF SERVICE

I am employed in the County of Yolo; my business address is 129 C Street, Suite 2, Davis, California; I am over the age of 18 years and not a party to the foregoing action. On July 25 2008, I served a true and correct copy of

[PROPOSED] JUDGMENT GRANTING PETITION FOR WRIT OF MANDATE

X (by mail) on all parties in said action listed below, in accordance with Code of Civil Procedure §1013a(3), by placing a true copy thereof enclosed in a sealed envelope in a United States mailbox in the City of Davis, California.

Martin Keck
Legal Division
Department of Transportation
1120 N Street (MS-57)
P.O. Box 1438
Sacramento, CA 95812-1438

Representing Respondents California Department of Transportation

I declare under penalty of perjury that the foregoing is true and correct. Executed on July 25 2008, at Davis, California.

Donald B. Mooney

GL14 Continued

Attachment E

Cervero, Robert
Beyond Travel Time Savings: An Expanded Framework or
Evaluating Urban Transport Projects
World Bank
2011

GL14 Continued

Transport Research Support

BEYOND TRAVEL TIME SAVINGS

ROBERT CERVERO

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GL14 Continued

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GL14 Continued

BEYOND TRAVEL TIME SAVINGS: AN EXPANDED FRAMEWORK FOR EVALUATING URBAN TRANSPORT PROJECTS

GL14 Continued

Transport Research Support

The Transport Research Support program is a joint World Bank/ DFID initiative focusing on emerging issues in the transport sector. Its goal is to generate knowledge in high priority areas of the transport sector and to disseminate to practitioners and decision-makers in developing countries.

GL14 Continued

CONTENTS

LIST OF TABLES

GL14 Continued

LIST OF FIGURES

GL14 Continued

ACKNOWLEDGEMENTS

The "Going Beyond Travel-Time Savings: An Expanded Framework for Evaluating Urban Transport Projects" has been prepared for the World Bank Transport Anchor group (TWITR) in Washington which administers and manages the Transport Research Support Program, TRSP, a financing of **DFID**, the Department for International Development of the United Kingdom Government.

We would like to express our thanks to Robert Cervero, Department of City and Regional Planning, University of California, Berkeley, who was contracted to provide the framework and the technical content. Roger Gorham, Economist, AFTTR, provided guidance and advice throughout the preparation of the study.

GL14 Continued

ABSTRACT

This paper challenges the widespread and often indiscriminant use of travel-time savings as a principal metric of economic benefits for evaluating urban transport projects. Time-budget theory and empirical evidence reveals that the benefits of a widened road or extended rail line often get expressed by more and longer trips to larger numbers of destinations and not by less time spent traveling. Induced travel demand can also erode time-savings benefits over the long term. Other conceptual and measurement issues related to travel-time reductions as a welfare measure are raised as well. A case is then made for elevating accessibility improvements as an outcome measure, particularly in light of the long-term nature of urban transport investments. Examples of measuring and monetizing accessibility are provided, although applying these techniques in developing countries is never easy. Still, tractability of measurement is no reason for relying on measures like reduced travel time when doing so flies in the face of theory, logic, and empirical evidence. The paper concludes that the World Bank should adopt a more robust and inclusionary framework for evaluating urban transport projects, one that supplements mobility-based measures like travel-time savings with metrics tied to accessibility, sustainability, livability, safety, and affordability. A preliminary plan of action is proposed in this regard.

GL14 Continued

1 INTRODUCTION

Travel-time savings are the principal economic benefit assigned to urban transport projects. Other benefits, like reduced vehicle operating costs (e.g., less wear-and-tear on vehicles; improved fuel economy) and accidents, are sometimes monetized as well. Because they are difficult to measure, less tangible second-order impacts, like improved air quality, are often treated subjectively in economic evaluations. According to Mackie et al. (2001), travel-time savings capture 80% of the quantified benefits for transportation Cost-Benefit Analyses (CBA) in the United Kingdom. In a recent evaluation of proposed bus-way improvements in Lima, Peru, travel-time savings represented 75% of the project's total estimated benefits (World Bank, Latin American and the Caribbean Region, 2003). World Bank studies likewise use travel-time savings as the chief measure of economic benefits — e.g., as an overall indicator in Monitoring and Evaluation (M&E) frameworks and Bank-sponsored CBAs.

This paper questions the focus on travel-time savings as the core and sometimes even exclusive metric of user benefits. History shows that major improvements to roads and public transit do not reduce the amount of time per day urbanites devote to getting around a city. More often, they increase the number and length of trips.

Despite dramatic gains in the average speed of travel conferred by modern technology over the past century — faster cars, super-highways, limited-access/grade-separated freeways — the amount of time urbanites spend traveling has remained largely unchanged over many decades, if not centuries. As transport systems become speedier and cheaper, urban dwellers take advantage of these improvements by traveling more and over greater distances as opposed to saving time or money. If conditions allow, users prefer to broaden their range of options rather than reduce general costs of travel. Thus, the benefit of a new road or bus-way gets expressed more in terms of expansion of trade-sheds, labor-sheds, market-sheds, and social networks than spending less on physical movement. Stated another way, the chief benefit is increased "accessibility" — i.e., the ability to get to destinations and activities people want to reach — not less total time traveling. It follows that any assessment of prospective transport investment projects should give at least as much attention to estimated impacts on accessibility as to travel-time savings.

Accessibility is a function of two main elements: (1) mobility – speed between point A and point B; and (2) location – distance between points A and B. In the near term, faster speeds either save time or allow more interactions between a fixed set of origins/destinations, possibly over a larger geographic catchment. Over the longer term, they allow origins and destinations to be

GL14 Continued

farther apart – which, when unplanned, equates to sprawl but when well-planned can increase opportunities for job searching, trading, and social interaction.

Metz (2008) has been particularly critical about the conventional practice of equating benefits to shrinking travel times. He asserts: "travel time savings has the quality of a myth — a traditional story accepted as factual" (Metz , 2008, p. 333). Travel time savings, Metz argues, are transient. In the short term, the prospect of travel time savings can influence when, along which corridor, and by which mode one travels. But once the new route becomes part of an established pattern of daily activity, the benefit should be viewed as an improvement in access rather than as a savings in travel time.

GL14 Continued

2 TIME-BUDGET THEORY

Arguments for focusing on enhanced accessibility vis-à-vis travel-time savings are rooted in time-budget theory (Zahavi and Talvitie, 1980, Tanner, 1981). Despite rapid increases in average travel speed, people continue to invest roughly the same amount of time to move about a city, on average an hour per day. This daily time budget has held remarkably constant over time, from ancient Rome to the walking cities of 15th century Europe to the streetcar suburbs of the early 20th century and freeway-laced cities of today. Time budgets are seemingly an anthropological constant, as if people are genetically pre-disposed to spend a fixed amount of time during their lives moving about cities and their surroundings. If a new road speeds up this movement, people simply move more often or farther. Traveling longer means the boundaries of cities have stretched outward as average speeds have increased.

Scholars have long cited transportation systems and technology as powerful forces that shape cityscapes and economic growth patterns (Warner, 1962; Wachs and Crawford, 1992; Garrison and Levinson, 2006). One can easily trace the outward expansion of cities to a succession of transportation advances that increased average travel speeds. The maximum size of walking cities was around 20 square kilometers, which supported settlements up to 50,000 or so inhabitants. When electric streetcars gained ascendency in the late 1800s, many cities quadrupled in size and with the advent of freeways the population and spatial extent of cities grew by several additional orders of magnitude (Schaeffer and Sclar, 1980; Muller, 2004).[1] Faster mobility has thus mainly changed the spatial organization of cities, not the amount of time devoted to travel.

Among the most persuasive evidence in support of time-budget theory is the following:

- In a study of world cities, Zahavi and Talvitie (1980) found a fairly constant amount of time and budget devoted to urban mobility — on average, around one hour per day moving about the city and around 11% of disposable income, with mean statistics three to four times larger than standard deviations.
- Zahavi (1979) also studied changes in travel patterns in the U.S. from 1958 to 1970, finding that Americans did not spend any less time traveling during a period when massive freeway construction let them travel considerably faster. A later study updated Zahavi's analysis

[1] A walking speed of 5 km/hour permits a 2.5 km return journey to be covered in one hour, producing a 20 km2 range (a circle with a 2.5 mile radius). With car travel ten times faster, the access area becomes one-hundred-fold larger — i.e., 2000 km2 (Lefevre, 2010).

GL14 Continued

using data through 1990, showing the earlier results still held (Barnes and Davis, 2001).

- Several other studies documented constancy in the amount of time, around 1.1 hours per day,that Americans invest in traveling (Ryan and Spear, 1978). McLynn and Spielberg (1978) found the one-hour-per-day figure held as early as 1840, a time when the first high-speed form of mechanized movement, steam-engine trains, spurred the industrial revolution and ushered in an era of decentralized growth in America.
- National surveys in the UK show that travel hours per person per year remained constant from 1970 to 2005 (around 350-380 hours), a period of massive motorway construction throughout the British Isles. According to Metz (2008), this implies "a long run value of travel time savings of zero". What is preferred is more and longer trips – average distance travelled shot up by 60% over the 1970-2005 period.

GL14 Continued

3 INDUCED TRAVEL DEMAND

Time-budget theory holds that supply-side improvements increase speeds which alter cities and travel distances. A related theory, called induced travel demand, contends supply-side improvements alter cities and travel so as to erode speed benefits. The two are flip sides of the same coin.

Critics of supply-side solutions to traffic congestion charge that the capacity-expanding benefits of most transport projects are short-lived. While all forms of transport investment influence travel, most complaints about the ephemeral benefits of added capacity are directed at the road sector. Figure 1 diagrams the flow of events attributed to the demand-inducing impacts of an expanded road. In the near term, increased capacity unleashes behavioral adjustments — e.g., trips previously suppressed are now made because of improved flows (i.e., latent demand); motorists switch routes, modes, or time-of-travel to take advantage of a new facility; motorists travel to destinations that are further away because of speedier flows (Downs, 1962, 1992; Cervero 2002; Noland and Lem, 2002). New trips, longer trips, and modal shifts contribute to increased Vehicle Kilometers Traveled (VKT), the strongest correlate to overall resource consumption and tailpipe emissions in the transport sector. Other adjustments, like route and temporal shifts, do not noticeably increase VKT and thus are largely redistributive in nature.

A meta-analysis found a mean short-term elasticity (between lane-km capacity and VKT) of several dozen roadway investments in the United States of 0.40 — i.e., all else equal, a doubling of road capacity was associated with a 40 percent increase in VKT within 1-3 years of the investment (Cervero, 2002). Over the long term, added road capacity led to more deeply rooted structural shifts, like increased car-ownership rates and more auto-oriented land-development patterns. Adding structural impacts to accumulated short-term ones markedly increases long-term elasticities — on average, 0.75 in the U.S. (Cervero, 2002). Other studies have estimated even higher long-term elasticities (Heanue, 1997; Fulton et al., 2000; Metz, 2008). Most empirical studies of induced travel demand have been conducted in the U.S. Metz (2008) has examined aggregate data to study nationwide trends in the UK. He found that average vehicle trip rates per household have changed little over the long run. This implies that induced traffic in the aggregate does not arise from increased journey frequency, retiming, or making entirely new additional journeys. Rather, Metz contends that induced traffic is generally the consequence of the choice of more distance destinations for the same journey purposes and is associated with changed land-use patterns. Metz also notes that induced traffic increases traffic accidents and vehicle emissions since they increase in lock-step with trip distances. Such factors should be adjusted in any long-range road project appraisal.

Overall, experiences reveal that travel adjusts to form a new equilibrium of traffic congestion following road improvements. This traffic-inducing and thus benefit-offsetting impact is incompletely accounted for by most economic appraisals of transport-facility investments (Downs, 1992; Saloman and Mokhtarian, 1997; Cervero, 2002; Cervero and Hansen, 2002; Ory et al., 2004).

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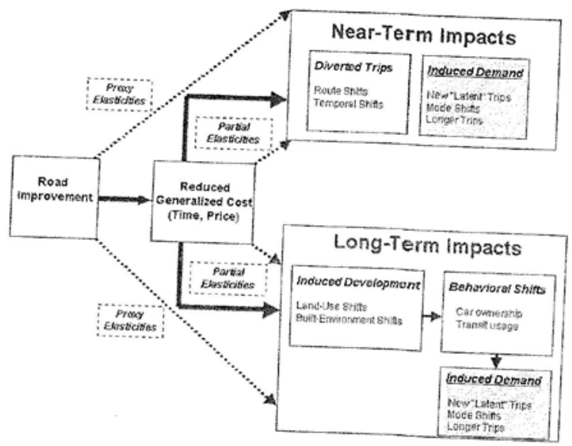
This is true in developing and developed countries alike.[2] Ignoring induced-demand impacts further calls into question the validity of relying on reduced travel times as the standard bearer for gauging the benefits of capital investments in roads and transit facilities.



The diagram shows near-term (i.e., first-order) and longer-term (i.e., second-order) impacts of expanded capacity. Initially, a road investment increases travel speeds and reduces travel times (and sometimes yields other benefits like less stressful driving conditions, on-time arrival, etc.); increased utility, or a lowering of "generalized cost", in turn stimulates travel, made up of multiple components, including new motorized trips (e.g., latent demand, previously suppressed), redistributions (modal, route, and time-of-day shifts), and over the longer term, more deeply rooted structural shifts like land-use adjustments

[2] There are rarely, if ever, adjustments for induced demand in travel forecasts of proposed urban transport projects in developing countries. Typically the subject matter is not even raised. Only a few World Bank appraisals of urban transport projects conducted over the past decade, such as in Hanoi and Lima, acknowledged that generated traffic or induced demand was not considered in estimating of travel-time savings.

GL14 Continued

and increased vehicle ownership rates (that in turn increase trip lengths and VKT). Some of the added trips are new, or induced, and some are diverted.

It is likely the case that the phenomenon of induced demand is more pronounced in the developing world than in most advanced first-world economies. Traffic gridlock creates a huge pent-up demand for mobility. Highly congested, poorly planned cities can thus expect to see the inducement of many newly generated trips following a roadway upgrade.[3] Over the long run, most new development in rapidly modernizing cities will gravitate to less-congested and newly expanded corridors, which are often on the urban fringes. In the Jakarta's, Nairobi's, and São Paulo's of the world — rapidly growing, bigger, denser, and poorer than their first-world counterparts — the transportation/land-use connection is robust, as are traveler responses to changes in road capacity and public-transport services.

[3] This is partly due to the archaic designs of central cities in many developing countries, often laid out to accommodate foot and bicycle traffic. The ability to retrofit urban cores with new transportation infrastructure is constrained in most instances and the costs of road construction thus tends to be quite high. Asian cities, for example, have 12% to 14% of land dedicated to roads compared to 25%-40% in US cities (Gwilliam, 2003).

GL14 Continued

4 TRAVEL TIME SAVINGS

This section discusses both conceptual and measurement challenges in operationalizing travel-time savings as a metric of economic benefits.

4.1 CONCEPTUAL CHALLENGES

Travel-time savings has been the centerpiece of transport economic analyses for approaching a half century (Small, 1992; Metz, 2008). Its popularity is as much due to the ease and convenience of measurement as to any theoretically grounded notion of why and how welfare — and particularly the welfare of the urban poor — would or should be improved by a transport investment.

There is a well-established literature on how to compare the benefits and costs of transportation proposals. Given the difficulty in determining how much consumers are willing to pay for, say, a new road, a common approach for imputing benefits is to multiply the predicted time savings to users by assumed values of time and sum the results (Mohring, 1961; Small, 1999; Banister and Berechman, 2000).[4] This has become conventional practice since total economic benefits are fairly easy to derive by comparing estimated total Vehicle Hours Traveled (VHT) "with" versus "without" a proposed improvement. Assumptions are needed, such as the estimated value of time, however even these often go unchallenged — e.g., 40% to 50% of a city's prevailing wage rate is what is typically assumed.[5] In developing countries, where current and reliable travel data are often in short supply and calibrated models are sometimes borrowed from elsewhere, potential errors from applying standardized and simplified approaches are likely magnified. In using computer-generated estimates of travel-time savings to gauge benefits, one must ask whether ease of measurement has usurped theory and logic?

Among the conceptual challenges faced in examining economic benefits and travel-time savings are the following:

- *Time Frame*. There can be a disconnect between the 40-50 year service life of most transport infrastructure and the near-term time horizon in which benefits are measured (given fixed land uses and thus fixed origin-destination patterns). CBA evaluates long-lived transport infrastructure based mainly on estimates of short-term

[4] Travel-time impacts of a specific road project are typically gauged throughout an entire network using the traditional four-step travel-demand modeling approach. This reflects the fact that the impacts of improving any single link reverberate throughout a network, affecting speeds and performance on other links as well. Impacts are also registered across modes. Proposed transportation investments, by saving travel time, generally influence model outputs by changing mode choice and route assignments. In more advanced models, such as when there is a feedback loop between the traffic assignment and land-use allocation phases, they may also influence trip generation and distribution.

[5] This practice applies to developed and developing countries as well as road and non-road projects. The Mumbai rail capacity upgrade study, for instance, similarly set the value of passenger time at 40% of average wage rate for users of different models (World Bank, South Asia Region, 2002).

GL14 Continued

travel-time savings. These near-term estimates might then be straight-line extrapolated to 50 years in the future without any adjustments in assumed future land-use (and thus origin-destination) patterns.

Over time, land markets shift as changes in accessibility patterns and housing filtration occurs, newly formed households trade off housing and transport costs to maximize utility, and a host of other dynamic forces are unleashed that reshape cities and travel. By the time that market effects of a transport investment have played out, it is never clear whether the per-capita amount of time spent traveling actually declines, particularly for the urban poor. As noted earlier, empirical evidence suggests it does not.

- *Scale of Analysis*. Benefits can vary widely by the geographic scale of analysis. At the corridor level, significant time savings might accrue among those traveling along a newly expanded 10-kilometer highway. However at a larger geographical scale (i.e., sub-regional "meso-scale" or regional "macro-scale"), more traffic might be induced by the addition of new and longer trips on existing roads, thus slowing speeds. The net impacts might be no changes in travel time for the sub-region or metropolitan area as a whole. While temporal changes might be most dramatic at a small geographic scale like a corridor, within an entire travel-shed or at the regional level – the scale most appropriate for drawing welfare judgments on public-policy interventions – spatial changes are likely to be most dramatic, especially over the long run (which, of course, is the time frame most appropriate for evaluating projects).

- *Travel Trade-offs*. Urban economic theory suggests that travel time alone is not a sufficient indicator of welfare because it is "traded off" against housing values (i.e. site rents) (Alonso, 1964; Muth, 1969). Dictated by consumer preferences and often stage-of-lifecycle, some households willfully endure long commutes in return for lower-cost housing on a per-square meter basis. Stereotypically these are younger families seeking larger living spaces (and in the U.S., often better schools). Also stereotypically, once the kids have gone off to college, some "empty-nesters" downsize by moving closer to the city, effectively trading off less time spent traveling for higher priced housing per square meter. Measuring changes in travel time alone thus ignores the reality that transportation and housing are a bundled good in the minds of many households. Thus a new freeway or rail line might induce some households to move farther out and thereby increase total time spent traveling in return for cheaper housing — a utility-maximizing choice made within the limits of a fixed transportation/housing cost budget. In such instances, studying impacts on travel times alone becomes meaningless.

- *Path Dependence and Infrastructure*. Once a dominant technology, like the auto-highway combination, gains ascendency, other modes can be marginalized as functional carriers, to the long-term detriment of a region at large. Mogridge (1997) argues that investing exclusively

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in road transport at the expense of other alternatives may cause a lower net welfare and higher congestion than a modally diverse investment strategy. He contends that roadway capacity expansion and similar congestion-mitigation policies actually increase travel times in the long-term in many urban settings. Building on theories of induced travel, Mogridge asserts that the modal convergence of switching from transit to auto travel in response to congestion-mitigation policies ultimately leads to deteriorating transit service, auto dependence, gross increases in travel time, and even more congestion. Perhaps car-dependent U.S. metropolises like greater Los Angeles and Houston provide the strongest empirical backing of this viewpoint. Despite averaging high levels of freeway capacity per capita, Los Angeles and Houston have over the past two decades consistently ranked as among the most congested areas in the country in terms of annual hours of delays per traveler (Schrank et al., 2010).

The obverse of this path dependency argument can be seen when tracing the impacts of pursuing a more balanced, multi-modal transportation program. In the case of Seoul, South Korea, for example, road capacity has been reduced in the core area (e.g., the Chenggyecheon freeway-to-greenway conversion; replacement of a large traffic circle in front of City Hall by an oval civic green), replaced by expanded Bus Rapid Transit (BRT) and other transit service reforms. Commercial and residential land prices increased following these road-to-amenity conversions (Kang and Cervero, 2009; Cervero, 2010; Cervero and Kang, 2011). In Seoul's case, property markets placed a higher premium on neighborhood quality, livability, and public amenities than mobility or swiftness of movement. Seoul's experience also demonstrate that the withdrawal of road capacity matched by stepped-up public-transport services can yield net welfare benefits.

- *Time Loss = Reduced Productivity?* Arguments that congestion-induced travel delay results in lost productivity are questionable, at least as a *carte blanche* assumption (Stopher 2004). While current research on traffic congestion attributes substantial economic drags to time losses or scheduling delays, it does not offer any guidance on whether these delays constitute foregone productivity. Transportation infrastructure is not productive in and of itself; rather the service and accessibility premiums it provides enable agglomeration economies or transport savings that function as direct inputs into productivity (Boarnet 1997). Although congested conditions may appear to be less productive than higher speed, non-peak conditions, many users clearly derive benefits from traveling during specific times (such as peak commuting hours) and to specific locations, despite the lower travel speeds. If an employee finds that his or her commute is 15 minutes longer due to congestion, he or she may leave for work earlier or may depart from work later in order to make up the additional work time. Also, 15 minutes of congestion delay would not replace economically productive time for an individual traveling to a social event after shopping. While foregone recreational time would certainly be valuable from a cost-benefit

analysis perspective, it is not economically productive (at least in the traditional sense of the word). Even for commuters, 15 minutes of delay might simply replace 15 minutes of idle time that would have been spent sometime during the workday or after work. Downs (1992; 2004) argues that time stuck in traffic is not necessarily stressful for some. Rather it might be the one time of the day when office workers enjoy solitude and quiet, comforted by the posh interior of a car playing relaxing music or having a novel recited on a high-end stereo unit. For some, sitting in an office bullpen separated by thin partitions from co-workers chatting on the phone might be just as stressful or unproductive.

4.2 MEASUREMENT ISSUES

Besides conceptual challenges, economic appraisals based on travel-time metrics face a number of practical measurement-related problems as well. These are discussed below.

- *Travel Surveys.* Data on travel times are usually obtained from self-reported travel diaries of a random sample of households in a region. This poses numerous problems, especially in cities of the developing world. One, informality and incomplete land registries make defining a population base from which to sample households virtually impossible. Since the poor most likely live in informal or itinerant settlements, they are most likely to be under-sampled. The same holds for any data collection instrument using random-digit dialing of telephone numbers since the poor are least likely to have a landline or cell phone. Two, travel-diaries presume literacy and because they are self-reported, are easily subjected to biased or incorrect responses. Such issues are again most likely to surface for low-income individuals and households. However biases can also be introduced by failing to compile data from the wealthiest members of society. A travel-diary survey of households in Bogotá, Colombia, for instance, recorded low response rates from not only the two lowest income strata but also the highest (Cervero et al., 2009).[6] In a city once known as the "kidnap capital of the world" and where narco-terrorist attacks still occur, most wealthy households have armed guards whose sheer presence deter surveyors from approaching their properties. Lastly, household surveys fail to capture non-home-based or non-household travel, such as by commercial trucks, taxis, paratransit/informal-transport, or inter-city through traffic.

- *Derived estimates.* Sometimes travel-time impacts are not estimated directly but rather derived from estimated future travel speeds and invoking the questionable assumption that trip origins and destinations will be unaffected by changes in transport system

[6] Under-sampling of the lowest income stratum was due to households living in squatter settlements and either being unavailable or unable to comprehend the purpose of surveys. Illiteracy and cultural factors (e.g., uncomfortability of having someone of a higher income stratum enter a tattered shelter) accounted for low response rates among the next-to-lowest income stratum.

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performance. This is common practice in the World Bank M&E framework. As already noted, smoother flowing traffic can unleash behavioral changes, such as the inducement of new trips or route shifts. Imputing travel times can also be problematic since trip durations often vary considerably from the statistical mean – e.g., by time-of-day, mode, section of corridor, etc. Imputing travel-time savings from average speeds is especially difficult in the developing world due to huge variations given the rather erratic and stochastic nature of traffic flows.

Computational errors are also possible when one invokes the simple assumption that changes in average speed and travel times are proportional. The current average speed is typically estimated by local traffic engineers using a floating car technique — i.e., a test car will pass as many vehicles that passes it over a defined distance, establishing a mean speed for a particular time-of-day. Say the recorded peak-period average speed for a hypothetical 10-km stretch of road is 40 kph. And assume a road improvement is expected to increase this figure to 50 kph. Ignoring issues of induced demand and induced growth effects, this is a 25 percent increase in mean speed. Does this mean average travel times similarly fell by 25 percent? Simple math shows this is incorrect (owing to different denominators used in measuring rates of change). It takes 15 minutes to cover the 10 km stretch at 40 kph and 12 minutes to do so at 50 kph. That's a 20 percent decline in mean travel time for a 25 percent increase in mean speed. Over a fixed distance, speed/travel-time trade-offs are not strictly proportional.

- *Absence of land-use adjustments*. The failure of the vast majority of travel-forecasting models to account for land-use adjustments poses a serious measurement problem in estimating travel-time benefits. The absence of any feedback loop from traffic assignment to land-use allocations implicitly assumes that trip origins and destinations do not change over time. As a result, Metz (2008) argues that the value of activities at trip ends "could be disregarded" since they are the same between the "do nothing" and "do something" alternatives. While travel demand might vary as a result of new infrastructure (as captured in trip distribution, modal split, and traffic assignment phases), the change in trip origins and destinations themselves (in the land-use allocation phase) is usually ignored. Thus, possible economic benefits of land-use adjustments — e.g., better matching of firms and labor; agglomeration economies from more efficient, clustered spatial arrangements; increased comparative shopping — get overlooked. Implicitly, this absence presumes no economic benefits are conferred by land-use adjustments. Assuming trip origins and destinations will not change following any transport-infrastructure enhancement flies in the face of theory, logic, and empirical evidence.

- Valuations. Time valuation stems from cost-benefit analysis (CBA) methods which compare the relative merits of two or more transportation alternatives. While researchers agree that the value of

time is related to the regional wage rate (Small 1992, Miller 1989), they do not agree on how to determine its present value. Many cite half of the wage rate, however the range extends from virtually nothing to values greater than the wage rate (Rouwendal and Nijkamp 2004).7 Some analyses apply specific values of time to different socio-economic groups, trip purposes, or times of day, while others use average estimates.8 Some research indicates that different trip lengths and savings increments are valued differently. There is likely an indifference zone wherein small time savings are imperceptible. Few people will notice a minute or two savings on a half-hour trip however 10 minutes of savings on a 30-minute trip will be impressionable. Due to the induced-demand/induced-growth phenomenon, most supply-side expansions are likely to shave a few minutes of travel time versus big perceptible savings.

Measuring value-of-time is more complicated for non-highway infrastructure. This is partly due to the predominance of road infrastructure in cities. Rarely will an investment in pedestrian infrastructure increase speeds and thus save time. New bike lanes might divert riders from faster direct routes and thereby increase travel times. For transit users, service reliability, transfer-free direct connections, and perceived levels of safety may be more heavily valued than time (Train, 2009). For such reasons, reliance on travel-time savings as the core metric of economic benefits of urban transport projects engenders a road-based bias.

[7] Small (1992) estimates that the value of time for trips range between 20% and 100% of a region's prevailing wage rate and estimates that 50% is a good rule of thumb for peak-hour users. Parry et al. (2007) give a rough estimate of total transportation costs per automobile mile in the U.S. — $0.05 attribute to congestion.

[8] A project appraisal of rail capacity upgrading, for example, set the value of time of high-income railway users at 2 ½ times higher than low-income ones (US$2.40 versus US$0.99 per hour) and those with formal jobs were assumed to value time twice as much as those with informal ones (US$2.73 versus US$1.30 per hour) (World Bank, South Asia Region, 2002). An appraisal of a bus-way proposal in Lima used a value of time of US$0.80 per hour for those traveling by private vehicles and US$0.31 for public transport riders (World Bank, Latin America and the Caribbean Region, 2003).

GL14 Continued

5 TRANSPORTATION PROJECT APPRAISALS OF THE WORLD BANK

Many of the issues discussed in the preceding sections apply to project appraisals conducted as part of loan packages for World Bank-funded projects. The economic appraisals of seven World Bank studies were examined in terms of their approach to measuring economic benefits [9] Most rely on travel models to estimate differences (with versus without improvement) in network-wide VHT (reflecting total system-wide travel-time expenditures). Some address other impacts, like reductions in accidents and air pollution, as a consequence of changes in both VHT and VKT. Benefits from reduced VHT and VKT are compared to estimated costs to come up with net present value (NPV) and Benefit/Cost ratios.

Few appraisals dealt with induced demand or any generated-traffic impacts that could erode travel time benefits over time. Most appraisals did not even acknowledge the possibility of induced-demand/induced-growth impacts. To the degree they are even used, it is not clear that travel-demand forecasting models contain feedback loops between traffic assignment and earlier input stages (including initial land-use allocations). Models appear to gauge near-term travel-time savings and assume these will remain fixed and unchanged over the life of a project, annualizing these values and extrapolating them over a set number of years — and in so doing, failing to account for land-use and behavioral adjustments. Travel-demand models do not appear to have been estimated in some of the poorest cities of the world, thus how travel-time savings are derived in these settings is unclear.

[9] Report sections on "economic evaluations" were examined for project appraisals of proposed loans and grants for urban transport projects in Ghana, Hanoi, Lagos, Lima, Mumbai, Rio de Janeiro, and Urumqui.

GL14 Continued

6 EQUITY CONSIDERATIONS

Reliance on travel-time metrics also raise equity concerns. Travel-time savings accrue mainly to motorists, yet many poor in the developing world — where most World Bank urban transport projects are targeted — do not own a car or drive. Their values of time might also be substantially less than those of the middle and professional classes. For them, enhanced access opportunities might be a bigger benefit – and contribute to the World Bank's over-arching objective of poverty alleviation — than reduced travel-time expenditures. The ability to widen the territorial sphere for job searching, saving on food purchases, reaching medical clinics, and seeking educational opportunities is likely to benefit the poor more than saving a few minutes of time moving along an expanded roadway.

Experiences also show that the poor are willing to trade-off travel-time delays for lower transit fares, parking rates, or fuel prices — i.e., they tend to be more price-sensitive and less time-sensitive than the non-poor. More popular uprisings have been sparked by increases in fuel prices and bus fares than by delays in travel times. For such reasons, the use of travel-time savings as a singular metric of benefits is all the more questionable from an equity point-of-view.

GL14 Continued

7 ALTERNATIVE MEASURES

The critiques of reliance on travel-time savings to gauge economic benefits does not mean they should be discarded. Rather they are just one of a number of measures that should be examined when weighing economic benefits of highway, public transport, and other transport infrastructure investments. A more complete palette of metrics for gauging benefits – one that includes changes in accessibility across a multitude of purposes – should be considered.

7.1 ACCESSIBILITY METRICS

So far, this paper has made the argument that one of the major benefits of expanding roadway capacity and transport services is to enhance access to places where travelers want to go. Access is a theoretical construct as opposed to a manifest behavior, and for this reason can be difficult to grasp. Access is about opportunities versus revealed choices and outcomes.

Besides more directly capturing the benefits conferred by transport investments, the inclusion of accessibility measures promotes a more balanced approach to long-range urban planning. Notably, it gives attention to alternatives to capital investments strategies for reducing traffic congestion and mitigating environmental problems, such as promoting efficient, resource-conserving land-use arrangements. This is because accessibility is a product of *mobility* and *proximity*, enhanced by either increasing the speed of getting between point A and point B (mobility), or by bringing points A and B closer together (proximity), or some combination thereof. Since accessibility is a product of both travel time and the geographic location of urban activities, it captures not only the temporal but also spatial dimension of travel. Thus accessibility measures give legitimacy to land-use initiatives and urban management tools in addition to supply-side, mobility-enhancing measures. Focusing on accessibility improvements as a goal reflects the "derived" nature of travel demand and puts the focus on promoting interaction — e.g., trade, social contacts, engagement with nature – versus movement per se. Some would argue most people want to minimize the time traveling so that more time can be spent at the destination. Framing the objective as making cities more accessible versus more mobile prompts a paradigmatic shift in planning, elevating land-use management and information technologies as bona fide tools for managing traffic flows and mitigating traffic congestion.

Measuring Accessibility

While there is a conceptual elegance to gauging benefits in terms of changes in accessibility, operationalizing this is not easy. For this reason, accessibility is typically handled qualitatively. The appraisal of a proposed BRT investment in Lagos, for example, offered a simple qualitative statement in support of the project on social grounds, noting "the proposed project would benefit women, the elderly, and the physically challenged by responding to their needs and providing them with *better access* to basic social services (health, school, administration), jobs, and markets, at a lower cost than currently available" (World Bank, Africa Regional Office, 2009, p. 26).

GL14 Continued

There are quantitative ways to gauge changes in accessibility. Going from concept to measurement involves mathematics and, increasingly, the power of Geographic Information Systems (GIS) tools. Two approaches are commonly used: (1) gravity-like measures (based on the denominator, or balancing factor, of a singly-constrained trip distribution model); and (2) isochronic measures (indicating the cumulative count of opportunities reachable within a given travel time or distance).[10]
Accessibility is normally measured for specific purposes – such as accessibility to jobs, hospital facilities, retail outlets, etc. In the case of job access, the two approaches to capturing access can be expressed as:

Gravity-based Index:

$AI_i = \Sigma j \, [\, Jobs_j \; * \; F_{ij}]$ where: $F_{ij} = \exp(-v \; Time_{ij})]$ or $F_{ij} = Time_{ij}^{-v}$ (1)

AI	= Accessibility Index
Jobs	= # of jobs in tract
Time	= network travel times
I	= residential zone
J	= employment zone
v	= estimated impedance coefficient

Isochronic-based Index:

$AI_i = \Sigma_j \, [\, Jobs_j \; (Time_{ij} \leq m)]$ where, in addition to above: (2)

M	= time threshold (e.g., 30 minutes)

Gravity-like measures of accessibility consider all trip-end possibilities within a defined study area in weighing the drawing power of potential trip attractions, corrected for the friction of distance or time in reaching them. However the AI value of a gravity-based measure is often meaningless unless compared to another value — such as the AI of the poor and non-poor or of auto-highway versus public transit options. Regardless of how they are measured, the value of an accessibility index, like any performance indicator, lies in a comparative context. According to Handy and Niemeier (1997, p. 1181), "no one best approach to measuring accessibility exists; different situations and purposes demand different approaches.

Isochronic measures receive high marks for their transparency and intuitiveness (Koenig, 1980). Anyone can relate to a value such as the presence of 200 hospital and medical-clinic beds within a half-hour bus ride as

[10] Other measures, like random utility and prism-based approaches, can be found in the literature, though these tend to be applied less often in practice, partly because of data limitations (Nishi and Kondo, 1992; Kitamura et al., 1998; Handy and Clifton, 2001).

GL14 Continued

a gauge of how accessible one is to medical care via transit. GIS allows isochronic measures to be visualized. Perhaps the biggest drawback of isochronic measures is they require the analyst to draw a time or geographic boundary for gauging access, which is sometimes arrived at subjectively.

Cross-City and Longitudinal Comparisons

As noted, accessibility metrics find most advantage when used as a comparative indicator, either between places or in a longitudinal context. Casiroli (2009) did a cross-city comparison of access to central tourist destinations in São Paulo (Praça de Sé) and London (Trafalgar Square) by mapping out how far one can get within 45 minutes (in green) and 90 minutes (in yellow) by car versus public transport in the evening peak (Figure 2). Summing the number of inhabitants residing within these travelsheds produces an isochronic measure of relative accessibility to these major leisure destinations by mode. Modal ratios reveals that more than twice as many Paulistas can reach Praça de Sé by private car than public transport in the P.M. peak. If reducing the carbon footprint of the transport sector and promoting more balanced transportation are long-range goals of São Paulo's transportation planners, then shrinking this differential over time would signal progress. A smaller ratio would also better reflect benefits accrued from improving metrorail and metrobus services than would an estimate of transit travel-time savings.

The accessibility profiles of competing transportation modes was recently studied over time in San Diego using isochronic metrics (Cervero, 2005). Figures 3 and 4 present comparative levels of job accessibility of those residing in the fast-growth Mission Valley area of San Diego via auto-highway and transit modes, respectively. Cumulative employment counts for 15-minute isochrones are also shown in each figure. The visual scan reveals that the near-ubiquitous road network in San Diego County covers a much larger geographic territory, and thus opens up greater access to jobs, than does the region's bus, light-rail, and commuter-rail systems. Not only are the isochrones in Figure 4 more geographically contained, they are also noncontiguous and spotty, indicating large gaps in transit service coverage.

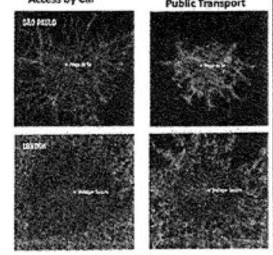
GL14 Continued

FIGURE 2: COMPARISON OF HOW FAR ONE CAN TRAVEL BY CAR VERSUS PUBLIC TRANSPORT WITHIN 45 AND 90 MINUTES IN EVENING PEAK, LONDON AND SÃO PAULO. ISOCHRONIC MEASURES ARE PLOTTED.

The Accessible City

How Far Can Travel in Evening Peak:
São Paulo vs. London

Access by Car | **Access by Public Transport**



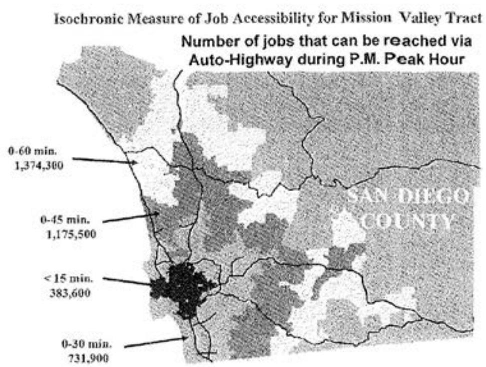
Differential Car vs. Public Transport	45 min.	90 min.
São Paulo	2.2	3.3
London	1.4	1.2

Green = 45 minutes
Yellow = 90 minutes

Source: Casiroli, *2009*

GL14 Continued

FIGURE 2. ISOCHRONIC MEASURE OF JOB ACCESSIBILITY IN SAN DIEGO COUNTY ON THE AUTO-HIGHWAY NETWORK FOR A MISSION VALLEY CENSUS TRACT, 2000. SOURCE: CERVERO (2005)



GL14 Continued

FIGURE 3. ISOCHRONIC MEASURE OF JOB ACCESSIBILITY IN SAN DIEGO COUNTY ON THE PUBLIC TRANSIT ROUTES FOR A MISSION VALLEY CENSUS TRACT, 2000. SOURCE: CERVERO (2005)

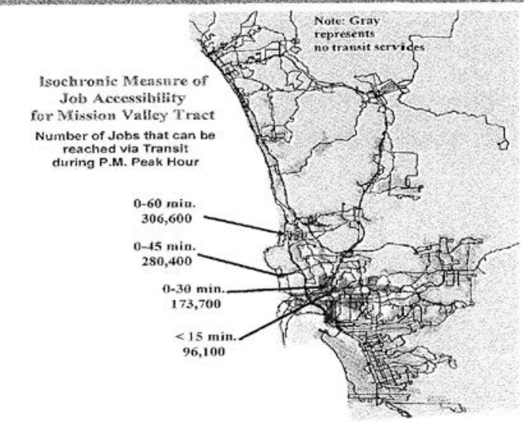


TABLE 1. COMPARATIVE JOB ACCESSIBILITY OF AUTO-HIGHWAY VERSUS TRANSIT FOR RESIDENTS OF SAN DIEGO'S MISSION VALLEY, 2000

Time Isochrone	A.I. Auto	A.I. Transit	Accessibility Advantage: Auto to Transit	MAG[1]
< 15 Min.	383,600	96,100	3.99	-.0559
15-30 Min.	731,900	173,700	4.21	-0.616
30-45 Min.	1,175,500	280,400	4.19	-0.614
45-60 Min.	1,374,300	306,600	4.48	-0.635

[1] MAG (Modal Accessibility Gap) = $(A^P - A^C)/(A^P + A^C)$, where A^P = AI of public transport and A^C = AI of private transport.

The comparative job accessibility advantages of auto-highway travel over public transit for residents of Mission Valley are shown in Table 1. Over all four travel-time rings, drivers enjoy a four-to-one accessibility advantage over transit riders. In general, the farther out one goes from the center, the job-

GL14 Continued

accessibility advantage enjoyed by motorists over transit users increases.[11] The comparative AI values were computed for 99 neighborhoods in San Diego in addition to the Mission Valley and averaged to derive a countywide comparative measure of job accessibility by mode. Also, smart-growth and business-as-usual plans for 2020 were compared not only in terms of conventional performance measures (like VKT and VHT) but also in terms of how they narrowed the accessibility disadvantages experienced by transit users. Transit-oriented growth could reduce the automobile's job-accessibility advantage by 60 percent in year 2020 compared to a business-as-usual scenario (Cervero, 2005).

In transit-oriented cities, the accessibility advantage enjoyed by motorists, such as in San Diego, would flip in favor of transit users. A recent study revealed that Hong Kong residents were far more accessible to jobs via the city's highly integrated network of public and private bus, metro-rail, tramway, ferry, and even funicular than via private car (Kwok and Yeh, 2004).[12]

Increasing Accessibility or Sprawl?

As discussed earlier, studies show that capital investments in roadways and transit lines appear to increase the number and length of trips more than reduce total travel times. Findings that people travel more and farther does not necessarily mean they do so by choice or derive utility in such behavior. Higher accessibility could reflect the impacts of sprawl — i.e., trip origins and destinations being farther apart, producing longer journeys, albeit at faster average speeds. Expanded travel-sheds can equate with increased benefits (e.g., productivity gains from better matching of firms' labor-input needs and workers' job preferences) but also high environmental and energy costs.[13] Accordingly to Siegel (2010), the yearly distance the average American drives doubles every few decades — from 4,009 miles per capita in 1960 to 9761 in 2000. Does this mean that levels of access or even quality-of-life for Americans have similarly doubled? It is for reasons like this that accessibility metrics should to be supplemented by others — including changes in vehicle miles traveled (VMT) and travel durations – in evaluating transportation proposals.

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[11] Table 1 probably understates the accessibility advantages of automobile travel because out-of-vehicle times in accessing and waiting for transit are generally understated in the zone-to-zone travel time estimates of transit.

[12] The computed MAG level (defined in the footnote of Table 1) for Hong Kong was 0.856 in 1996, down from 0.937, meaning the big accessibility edge enjoyed by public transport eroded some during the 1990s. Zero MAG values indicate equal accessibility among modes while values close to one (in absolute terms) denote extreme disparities.

[13] Similar arguments can be made about expanded housing choices. Under the theory of choice, households search to find the right combination of public services and accessibility so as to maximize their utility. Those seeking to minimize commuting are likely to pay higher real-estate prices for job-accessible locations (Alonso, 1964; Muth, 1969). Thus expanded accessibility can mean expanded residential choice sets.

GL14 Continued

7.2 Monetizing Accessibility Benefits

While accessibility indicators are useful metrics for inter-modal comparisons and assessing likely impacts of transportation and land-use plans over time, they need to be expressed in monetary terms if they are to be of much use in economic appraisals. Consumers no doubt benefit from having more retail outlets to choose from. Employers similarly benefit from an enlarged laborshed from which to seek out new workers and fitness buffs benefit from having more recreational opportunities within a half hour of their residences. Assigning an economic value to such benefits, however, is challenging.

Willingness-to-Pay Approach

One approach to valuing access is to measure willingness-to-pay, applying stated preference techniques (Metz, 2008). Using various scenarios, residents might be asked how much they would be willing to pay for increased access to shopping choices. Or businesses might be asked about their willingness to pay for shaving an average of 5 minutes off the daily commute of their work forces. The willingness-to-pay approach, of course, relies on subjective responses to "what-if" scenarios. It presumes respondents have the capacities to carefully weigh and value options and to make informed choices, even if they have no first-hand experiences with those choices.

Land-Value Capitalization

The impacts of increased accessibility get expressed in land prices. There is a finite, limited supply of good, accessible locations in a city. In a reasonably well-functioning marketplace, those seeking accessible locations to open a shop or business will bid up the price for well-located, accessible properties. Land markets thus capitalize the benefits of accessibility.

To gauge capitalization benefits, hedonic price models are widely considered to be the best method available. Hedonic price theory holds that most consumer goods comprise a bundle of attributes and that the transaction price can be decomposed into the component (or 'hedonic') prices of each attribute (Rosen, 1974). Using estimation approaches like ordinary least-squares regression, hedonic price models apportion sales-transacted real-estate values among causal explainers, shedding light into the marginal contribution of factors like accessibility, land-use type, and neighborhood quality.14 For purposes of gauging land-value benefits, hedonic models generally take the form: PI = f(L, N, C), where PI equals the estimated price (per square meter) of parcel i; L is a vector of location and regional accessibility attributes (e.g., accessibility to jobs); N is a vector of neighborhood characteristics (e.g., presence of mixed land uses; median housing income); and C is a vector of

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[14] Many studies use data on rents as opposed to sales prices for real-estate transactions (that are open, arms-length transactions). Rental data can be problematic, however, in that contract rents do not always capture the full array of concessions received by tenants. Even if contract rents are fairly accurate, they need to be adjusted for occupancy levels to reveal effective contract rates. Data limitations often preclude this. Focusing on sales transaction data avoids such problems.

GL14 Continued

controls (e.g., fixed-effect variables).

Table 2 presents hedonic-price model findings on the impacts of accessibility on real-estate prices in San Diego (Cervero, 2004). This was part of a larger study on the capitalization effects of proximity to San Diego's light-rail transit line. Only the output pertaining to the impacts of Accessibility Indexes on single-family home prices are shown in the table. The model, which explained 60 percent of variation in housing prices, shows that single-family homes fetched more than $1,000 for every 1,000 additional jobs within 30-minutes peak travel time, all else being equal. Employment access via transit increased the value of single-family homes even more: for every 1,000 additional jobs within 15 minutes travel time by bus or rail, sales value rose by nearly $6,300, holding other factors constant. Clearly, home-buyers in San Diego placed a high premium on job access by public and private modes of commuting, consistent with residential location theory.

[illegible]

Variable	Coefficient	Standard Error	Prob. Value
Accessibility			
Regional Job Accessibility, Highway: Number of jobs (in 1,000s, 1995) within 30 minute peak-period auto travel time on highway network	1,042.0	160.4	.000
Regional Job Accessibility, Transit: Number of jobs (in 1,000s, 1995) within 15 minute peak-period transit travel time on transit network	6,286.5	710.2	.000

Control variables in model: attributes of property (e.g., size, location); attributes of buildings (e.g., size, number of bedrooms); attributes of neighborhood (e.g., median household incomes; school scores); municipal fixed effects.

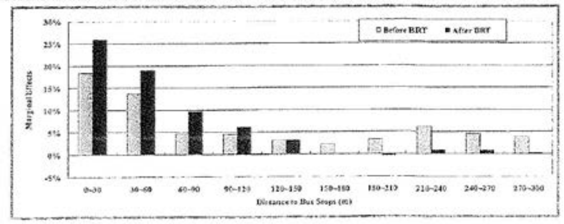
N = 14,576
R^2 = .605
Source: Cervero (2004)

A more recent study of upgraded Bus Rapid Transit (BRT) services in Seoul, South Korea similarly relied on hedonic price modeling to assess impacts on both residential and commercial real-estate market performance (Cervero and Kang, 2011). The study focused on how changing from a modest BRT curbside-lane configuration to a more substantial dedicated center-lane operation got capitalized into retail-commercial land prices. Data were compiled for more than 37,000 commercial real-estate properties within an estimated impact zone of the BRT-upgrade project for two time periods: 2001-2004 (curbside operations) and 2005-2007 (center-lane operations). Multi-level modeling was used to estimate benefits of proximity, or access, to the BRT corridor before and after the upgrade. The coefficients on dummy variables that measured the shortest walking distance of commercial parcels to the nearest BRT indicated whether proximity affected land prices differently

GL14 Continued

before and after the BRT improvements. Figure 5 plots these coefficients, revealing the marginal effects of proximity on land prices, expressed in percentage terms and over 30 meter distance bands, relative to parcels more than 300 meters away (defined as the impact zone of the project). While access benefits accrued to those living near BRT corridors in both periods, the figure reveals the benefits were more prominently capitalized into land values in the post-period (2005-2007). Benefits were the greatest within 150 meters of the nearest BRT stop. A recent study of access to rail lines in Bangkok found similar results, with the premium of transit accessibility estimated to be $10 for every meter that a property lies closer to a station (Chalermpong, 2007).

Figure 5. Marginal Effects of Walking Access to BRT Bus Stops on Commercial Land Values in Seoul over Distance Intervals. Source: Cervero and Kang (2011)



Hedonic modeling results such as those reviewed above express a monetary premium conferred by accessibility improvements. For purposes of estimating a total economic benefit, the per square-meter premium needs to be multiplied by the number of square meters within the estimated impact zone of a project.[15] If, for example, the mean land-value premium of a transportation improvement is $10 per square meter and this benefit extends over 100 hectares (or one million square meters), then the project's economic benefit could be set at $10 million. Values might be adjusted to reflect changes in capitalization impacts over time (e.g., over the service-life of a capital project) or over space (e.g., reflecting the fact that premiums vary geographically, such as shown in Figure 5).

The presence of land-value premiums should not be added to the monetary value of travel-time savings. To do so would be to double-count since land values embody travel time savings. If consumer benefits are measured as a function of hours of travel saved multiplied by value of time per hour, changes in land values, which capitalize these benefits, should not be included as a benefit (Mohring, 1961; Small, 1999; Banister and Berechman, 2000). Thus,

[15] For more on this method of estimating total economic benefits using hedonic-price model results, see Cambridge Systematics et al. (1998).

GL14 Continued

accessibility benefits should be treated as a supplement to travel-time metrics or an alternative perspective for gauging impacts, not an un-related add-on.[16]

Applying land-value capitalizations to measure accessibility might be problematic in many developing countries. The absence of well-functioning land markets in some poor countries could distort estimates. Informality, complex patterns of land tenure, and incomplete land registries pose further hurdles (Törhönen, 2004). One approach might be to estimate shadow land prices however doing so for a multitude of informal parcels within the impact zone of a transport project might be impracticable.[17] Chalermpong (2007) states that very few hedonic studies have been published on the effect of transit accessibility on property values outside North America and Europe because data are often unreliable or non-existent. It could be that land markets in developing countries engender so many distortions and misallocations that reliably imputing accessibility benefits from land price data is nearly impossible. For these reasons, the use of accessibility indices as comparative and longitudinal measures — and as supplements to travel-time savings estimates — might be the best one can hope for in many developing country settings.

7.3 Economic Development Impacts

The benefits of increased accessibility can also be expressed in terms of second-order effects on net economic growth in a region. This might be done using an input-output model that enumerates inter-industry production and linkages that occur as a consequence of, among other things, improved access to factor inputs (e.g., labor, raw materials) and markets. Economic forecasting and simulation models, such as REMI, can use accessibility along with other input metrics to predict changes in business output, sales, gross regional product, employment, and population over a specified time horizon.

Economic development impacts are typically treated as a second-order "add on" benefit of transportation projects in urban settings. In rural areas, however, they can very well be the chief economic benefit. In most rural parts of developing countries, traffic levels are too low for there to be any measurable benefit of a roadway investment using conventional consumer surplus measures. However the prospect of stimulating trade and increasing agricultural production might be substantial. A recent evaluation of a proposed road upgrade between northeast Congo and the Central African Republic used a gravity model to estimate that goods traded via this route

[16] Also, as with estimated travel-time savings, estimates of capitalized land values likely provide a lower-end range of benefits conferred by an improved road or transit facility. This is not only because accessibility improvements fail to capture external benefits (e.g., improved air quality) but also because they ignore some of the non-derived, psychological benefits of movement (Metz, 2008).

[17] This might be done by using sales-transacted prices of formal, registered properties with similar levels of accessibility (based on regional location and proximity to transport infrastructure) as an informal property of interest, adjusting for differences in site (e.g., presence of piped versus non-piped water supply) and neighborhood (e.g., median income) characteristics. For more on shadow pricing of land market responses to transport-sector interventions, see Arnott and MacKinnon (1978).

GL14 Continued

would increase from a current value of US$16 million to US$142, nearly a 800 percent increase (Buysa et al., 2010). The study concluded that trade expansion promoted by the upgrading would exceed costs by about $220 billion over 15 years, while generating millions of construction and maintenance jobs in some of Africa's poorest regions. While trade volume expansion is not a direct measure of welfare improvement, estimates of the growth and income-inducing effects of increased trade can reflect generative (as opposed to redistributive) benefits and thus should be weighed in investment decisions (Frankel and Romer, 1999).

7.4 Cost-Effectiveness Measures

Rather than attaching a monetary value to transportation improvements, cost-effectiveness measures might be used instead. A cost-effectiveness metric might express the number of additional jobs that can be reached within one-half hour travel time per million dollar expenditure. Thus instead of attempting to assign a monetary value to benefits (e.g., increased access to jobs), only financial costs for project outlays are monetized. Combining data on financial expenditures with isochronic indices of accessibility can yield a reasonable performance measure that is free of such problems as valuing time or obtaining land valuation data.

Cost-effectiveness measures are likely better suited to many developing countries where reliable data are limited and outcomes are difficult to measure. Cost-benefit analysis is not used in evaluating public works projects — like a school building upgrade — when inputs cannot be easily translated to outcomes (e.g., higher student scores). Similar challenges in attributing transportation investments to accessibility outcomes argue for cost-effective measures as a second-best alternative in some instances.

GL14 Continued

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8 Conclusion

The widespread and indiscriminant use of travel-time reductions as a stand-alone indicator of success in World Bank appraisals of urban transport projects is inconsistent with economic and spatial theories of how cities grow and function. In congested, fast-growing cities with a pent-up demand for mobility, unchecked sprawl, and correspondingly high induced-demand elasticities, travel-time savings is likely a poor measure of welfare benefits from transport interventions, policy changes, and capital investments.

The established practice of relying on time savings as the principal measure of economic benefit of urban transport projects needs to be questioned. Metz (2008, p. 324) echoes this view: "Data on average travel time offer no obvious support to the idea that travel time savings comprise the dominant element of the benefits from investments in the transport system". There is stronger evidence that people take advantage of transport system expansion in the form of additional access to desirable destinations, made possible by faster speeds within the fairly fixed budgets of time available for travel. Metz (2008, p. 325) adds that "given the long-term invariance of average travel time, travel time savings would necessarily be a transient phenomenon, in a context in which individuals tend to use improvements in the transport system to maximize access". Time savings is thus largely a short-term benefit. Over time, people tend to make longer journeys, not extra trips. Weighing impacts on accessibility thus brings a longer term perspective to the analysis, something that is needed given the fifty-plus year service life of most capital-intensive transport investments.

Concerns over induced travel, global warming, and auto-dependent cities call for a more balanced, holistic approach to evaluating future urban transport projects. Framing evaluations in terms of accessibility, not just mobility, allows a shift from a traditional engineering focus on speed and efficiency to a more balanced perspective that weighs environmental and social concerns as well. Additionally, assessing impacts on accessibility elevates the importance of land-use and demand-management strategies in the evaluation of alternatives. Besides accessibility and mobility (e.g., speeds), a more robust and inclusionary framework for measuring performance might also weigh factors like sustainability (e.g., VKT and emissions per capital), livability (e.g., community ratings or commute delays per capita), safety (e.g., road fatalities per 100,000 inhabitants), and affordability (e.g., percent wages spend on commuting) in judging proposals.

To date, accessibility has been treated qualitatively in most project appraisals of World Bank urban transport sector loans. It is not examined with the same rigor as projected travel-time savings. An evaluation of BRT proposals in Accra, Ghana, for example, used a qualitative scoring approach, subjectively giving "accessibility for low-income populations" a weight of 21.4% in judging competing corridors (World Bank, Africa Region, 2007). Many appraisals simply mention improved access in a list of "social benefits" as an adjunct to economic appraisals based mostly on savings in travel time and vehicle operating costs. Separating mostly quantified "economic benefits" from non-quantified "social benefits" gives the impression that accessibility impacts are

secondary and non-pecuniary.

Elevating the importance of accessibility and other performance measures like sustainability in project appraisals need to be done with equity concerns in mind. If improved access to jobs, shops, and hospital services are limited to car-owning households, little progress will be made in alleviating urban poverty. It is thus important that all performance metrics stratify results in ways that allow the likely distributional equity impacts of a project to be assessed. Additionally, measures of affordability should be directly used as an indicator, in and of itself.

Our choices for evaluation are fortunately not "either/or" — travel time savings or accessibility. In fairly homogeneous small-town settings where growth rates are modest thus few land-use adjustments might be expected, travel-time savings might be an appropriate way to gauge benefits. In others, say in fast-growing cities where induced demand phenomenon is alive-and-well, as much focus might be placed on measuring accessibility impacts. In tandem, travel-time savings and accessibility shifts provide a rich perspective for exploring the economic benefits of proposed transport projects. When supplemented by other outcome measures, like impacts on the environment, safety, and vehicle operating costs, the two can provide a fairly complete portrait of future economic benefits

GL14 Continued

9 NEXT STEPS

This paper argues for an enlarged, more inclusive set of indicators for evaluating transportation proposals in the developing world, most notably elevating the role and importance of accessibility improvements as a metric. How might this theory be put into practice? Given the reality that current appraisal methods are deeply entrenched and institutionalized, small, measured steps should be taken. Accordingly, a pilot demonstration is proposed. The aim should be to develop, refine, and apply a practical "tool-kit" of indicators for evaluating alternative urban transport proposals.

By way of illustration, this tool-kit might involve the following set of indicators:

First-Tier Indicators (with and without induced travel/induced growth adjustments):

- Total travel times
- Vehicle operating costs
- Collisions and accident injuries/fatalities

First-tier indicators could be measured using conventional methods, with the exception that adjustments would be made for estimated induced travel/induced growth impacts. Such adjustments might occur through feedback loops in 4-step models or through post-processing (i.e., applying induced travel/induced growth elasticities derived from comparable projects or provided as meta-analysis averages) [See: Cervero, 2006]. First-tier indicators might be further stratified by time-period (e.g., peak; all-day) and modes-of-travel.

Second-Tier Primary Indicators (with and without induced travel/induced growth adjustments):

- Environmental conditions (air pollution, noise pollution, visual impacts)
- Economic development impacts (employment, businesses, monetary value of private investments)

Second-order impacts generally reflect longer-term, delayed responses to changes in the urban transportation system. Conventional methods might be used, such as translating VKT and VHT impacts to air pollution levels using emissions-diffusion models. Economic development impacts might be estimated by applying techniques like shift-share forecasting, regional input-output modeling, or econometric/structural-equation modeling. Due to data and modeling limitations, more qualitative methods (e.g., expert-Delphi scoring) might be used in many developing country contexts to get at such hard-to-measure second-order impacts. In gauging impacts on economic development, care must be taken to distinguish those that are redistributive or pecuniary in nature versus those that are truly generative and income-

GL14 Continued

producing.

Second-Tier Supplemental indicators (with and without induced travel/induced growth adjustments):

- Accessibility (jobs; medical facilities; education; retail-commercial)
- Sustainability (e.g., change in VKT per capita; change in VKT per motorist)
- Livability (e.g., percent change in trips by non-motorized transport by income strata; percent of peak-period traffic > 40 kph; percent green-space per capita; ratio of public green space to public impervious surfaces (i.e., parking and roads);
  lineal kms of bikeways/sidewalks per 10,000 inhabitants)
- Affordability (e.g., percent daily earns spent on transport; mean monthly transit fare payments to mean monthly income)

These supplemental second-tier indicators round out the evaluation framework by accounting for a wider array of impacts that go beyond those affecting direct users of transport facilities or services. Depending on the availability of suitable data, accessibility impacts could be gauged using a isochronic cost-effectiveness measure (e.g., change in mean number of hospital and clinic beds that can be reached within 30 minutes by public transit — an indicator of "medical access by transit" — per $1 million in investment costs). Or accessibility impacts could be monetized using hedonic-price methods. Alternatively, subjective scoring approaches might be used. In general, qualitative methods will need to be relied on to the extent that network-based travel-demand forecasting tools are unavailable for estimating impacts on VKT and VHT.

These multiple tiers of impacts are not additive. They represent overlapping Venn diagrams. Accordingly, trying to combine and force these metrics into a Cost-Benefit Analysis framework would be futile and yield erroneous results. Rather, consideration might be given to assigning relative weights to the indicators, based on local circumstances and expert opinions.

In closing, consideration should be giving to pilot-testing and operationalizing the expanded evaluation framework presented in this paper. This would involve choosing a case site and project, identifying appropriate indicators based on local conditions and data resources, and carrying out the evaluation. Field testing is the best way to move the theories and ideas expressed in this paper one step closer to implementation.

GL14 Continued

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Attachment F

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Cardiovascular health and particulate vehicular emissions: a critical evaluation of the evidence

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Abstract A major public health goal is to determine linkages between specific pollution sources and adverse health outcomes. This paper provides an integrative evaluation of the database examining effects of vehicular emissions, such as black carbon (BC), carbonaceous gasses, and ultrafine PM, on cardiovascular (CV) morbidity and mortality. Less than a decade ago, few epidemiological studies had examined effects of traffic emissions specifically on these health endpoints. In 2002, the first of many studies emerged finding significantly higher risks of CV morbidity and mortality for people living in close proximity to major roadways, vs. those living further away. Abundant epidemiological studies now link exposure to vehicular emissions, characterized in many different ways, with CV health endpoints such as cardiopulmonary and ischemic heart disease and circulatory-disease-associated mortality; incidence of coronary artery disease; acute myocardial infarction; survival after heart failure; emergency CV hospital admissions; and markers of atherosclerosis. We identify numerous in vitro, in vivo, and human panel studies elucidating mechanisms which could explain many of these cardiovascular morbidity and mortality associations. These include: oxidative stress, inflammation, lipoperoxidation and atherosclerosis, change in heart rate variability (HRV), arrhythmias, ST-segment depression, and changes in vascular function (such as brachial arterial caliber and blood pressure). Panel studies with accurate exposure information, examining effects of ambient components of vehicular emissions on susceptible human subjects, appear to confirm these mechanisms. Together, this body of evidence supports biological mechanisms which can explain the various CV epidemiological findings. Based upon these studies, the research base suggests that vehicular emissions are a major environmental cause of cardiovascular mortality and morbidity in the United States. As a means to reduce the public health consequences of such emissions, it may be desirable to promulgate a black carbon (BC) $PM_{2.5}$ standard under the National Ambient Air Quality Standards, which would apply to both on and off-road diesels. Two specific critical research needs are identified. One is to continue research on health effects of vehicular emissions, gaseous as well as particulate. The second is to utilize identical or nearly identical research designs in studies using accurate exposure metrics to determine whether other major PM pollutant sources and types may also underlie the specific health effects found in this evaluation for vehicular emissions.

Keywords Vehicular · Diesel · Cardiovascular · Exposure · Ambient · Epidemiology · Air pollution

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Introduction

Method of assessing effects of vehicular emissions on cardiovascular endpoints

A considerable literature base is now available relating cardiovascular (CV) health effects from exposure to ambient particulate matter (PM) deriving from various sources. Specific components of PM from such sources—

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which are heterogeneous physically and chemically—will likely have differential health impacts.

Vehicular emissions consist of particulate and gaseous emissions, with biologically active carbonaceous products present in both phases. Black carbon, mainly from diesels, is found in ultrafine and fine size fractions, mainly less than 1 μm in size and predominantly below 0.18μm (Mauderly and Chow 2008). Such vehicular particulates are often coated with condensed organic and inorganic compounds (Mauderly 2001; Health Effects Institute 1995). Approximately 75% of diesel $PM_{2.5}$ emissions consist of such carbon (Health Effects Institute 2003). While particulate vehicular emissions per se, notably in the ultrafine fraction, have been specifically associated with endpoints such as oxidative stress and mitochondrial damage (Li et al. 2003), lipid peroxidation (Pereira et al. 2007), upregulation of genes relevant to vascular inflammation (Gong et al. 2007), and early atherosclerosis and oxidative stress (Araujo et al. 2008), non-particulate emissions have also been specifically linked to a variety of health endpoints (Mauderly and Chow 2008).

Our evaluation begins with the considerable amount of epidemiological evidence which has become available mainly since 2002 linking vehicular emissions with a range of CV outcomes. We then examine in vitro, in vivo, and human panel studies to understand if biological mechanisms have been identified in such studies which would explain the epidemiological findings for each CV outcome. Many of these studies use diesel emissions or diesel emission particulates, or evaluate effects from ambient air collected near highways in major cities with associations found with black carbon, mainly a diesel emission. Thus, our assessment assesses the coherence of results across different methodologies for CV endpoints, related to vehicular emissions.

Interpretation of studies related to accurate exposure assessment

Before reviewing epidemiological evidence linking vehicular emissions with CV endpoints, it is important to understand how differences among studies in accuracy of subject exposure to spatially variable emissions such as vehicular emissions can affect the strength and biological significance of associations.

Many epidemiological and panel studies use data from central monitors to characterize exposure to pollutants which may have considerable local variability and thus do not accurately characterize subjects' exposure to these emissions (Ito et al. 2004). Using central monitors or other less precise exposure estimation methods will result in underestimates of risks (Zeger et al. 2000), including those from vehicular emissions (Adar and Kaufman 2007). In multi-pollutant models, differential exposure error may cause risks to be transferred from variables having more exposure error to those having less (Goldberg and Burnett 2003; Hennekens and Buring 1987). Thus, it is essential to understand to what extent currently available studies include accurate assessment information for pollutants that might be particularly harmful, and to assess how these exposures relate to the magnitude and significance of risk estimates. This type of evaluation is necessary to determine whether emissions from specific sources rather than others may be more critical to regulate so as to preserve public health. Even with subject exposure misclassification, positive significant associations are not ruled out; however, in such a case, they are likely understated (Zeger et al. 2000).

This paper attempts to address these issues for vehicular emissions as they relate to CV health endpoints, with emphasis on epidemiological investigations incorporating reasonably accurate subject exposure information. We define "reasonably accurate exposure" as that exposure metric resulting from a methodology in which the measured exposure concentration varies with and, therefore, reflects reasonably closely the actual exposure for the population that is being assessed for adverse health outcomes. Methodologies which meet this criteria would include (1) personal monitors, (2) monitors which follow subjects closely as they go about their daily activities, (3) studies which use a combination of wind trajectories and pollution measurements to understand what sources were influencing exposure in the time period(s) of interest, and (4) studies in which the monitor was in close proximity to a roadway, and the subjects of the study also lived in close proximity to the same roadway not far distant from the monitor (Grahame 2009). On the other hand, an epidemiological study using a central monitored concentration and using this concentration as an exposure metric for subjects living over a wide area represents inaccurate exposure for traffic-related emissions, because such emissions have substantial variance across a city (Ito et al. 2004) and even within 100 m of a major highway vs. further away (Zhu et al. 2002a, b). A fuller discussion of these issues is found in Grahame (2009), which considers formally whether health effect associations vary consistently among studies which use reasonably accurate subject exposure information for spatially variable emissions such as BC, vs. studies using centrally monitored concentrations as a proxy for exposure to such local emissions.

The vehicle/traffic emissions category was selected since there is a large and growing evidence base suggesting that traffic-related pollution likely plays an important role in adverse health outcomes associated with ambient pollution such as urban PM, including black carbon (BC; White et al. 2005; Samet 2007; Adar and Kaufmann 2007;

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Li and Nel 2006; Delfino et al. 2008), the latter derived primarily from diesel engines.

We first consider epidemiological studies which utilize information relating proximity of residence to major roads, to determine the extent to which such proximity may be associated with health outcomes such as all-cause or cardiovascular mortality and morbidity. Some of these studies examined associations of specific vehicular emissions, e.g., BC as a marker of diesel emissions, with such outcomes. Similar studies use modeled exposure to vehicular emissions (BC, or mainly outside the U.S., NO_2) at the residence, or use traffic density as a proxy for exposure to vehicular emissions (at county level or within 100 m of the residence).

We then consider studies which examine specific CV biological endpoints, e.g., oxidative stress, inflammation, change in EKG pattern (ST-segment depression), changes in heart rate variability (HRV), vasoconstriction and changes in blood pressure, arrhythmias, and lipoperoxidation/atherosclerosis. Such studies can vary considerably in accuracy of subject exposure; again, we emphasize findings from studies with more accurate exposure information. Toxicological evidence regarding specific biological mechanisms is also examined to understand if there might be common threads which extend from toxicological through panel studies to epidemiological evaluations.

Associations between vehicular emissions and lung cancer, and mutagenicity of vehicular emissions, have been reviewed elsewhere (Grahame and Schlesinger 2007) and will not be reviewed here. Similarly, the ample literature relating vehicular emissions and highway proximity to respiratory morbidity endpoints, such as asthma, will not be discussed.

Epidemiological evidence for association of vehicular emissions with adverse cardiovascular health outcomes

Investigating health effects specific to vehicular emissions in epidemiological studies has historically been problematic. Early studies did not monitor for pollutants most closely related to vehicular emissions (e.g., BC) and, thus, could not find associations with such emissions. Later reanalyses of the early studies were sometimes able to parse out such associations, despite the lack of vehicular pollution data (e.g., the Jerrett et al. 2005 reanalysis of the American Cancer Society cohort [Pope et al. 1995, 2002]). When studies began to monitor specifically for vehicular emissions such as BC, initial exposure assessment used central monitor data and associations were often not robust. NO_2 is also seen as a marker of vehicular emissions, particularly in European studies. Although NO_2 is emitted from sources other than vehicles, such as power plants and industry, vehicular NO_2 emissions usually dominate in busy urban centers lacking major industry. In some cases, where monitors were located in close proximity to major highways, even SO_2 and/or SO_4 from different sources, including diesels before the 2007 changeover to ultra-low sulfur diesel fuel, may be intermixed (Grahame and Hidy 2007a, b).

Studies using central monitoring for several different sources, including vehicles, did not always find daily mortality or morbidity associated with vehicular emissions. For example, Thurston et al. (2005) failed to find cardiovascular or non-accidental mortality associated with a traffic emissions factor in either Phoenix or Washington, DC, using different source apportionment models. However, the daily mortality study of Laden et al. (2000) found such associations, as did the Schwartz (2003) reanalysis of Laden et al. (2000), necessitated by problems in the original study with a statistical software package (which affected many other studies as well). Another multi-city study (Janssen et al. 2002) examined prevalence of air conditioning as an effect modifier, and found associations for daily morbidity (hospital admissions for CV disease) with diesel emissions, highway emissions, and vehicle miles traveled per square mile (traffic density). Two recent studies based in Atlanta (Sarnat et al. 2008; Tolbert et al. 2007) found significant associations between vehicular emissions and emergency department admissions for CV disease. However, Metzger et al. (2007), in a study also in the Atlanta area, failed to find associations between PM_{10}, $PM_{2.5}$, or vehicular emissions with daily morbidity (i.e., arrhythmias).

Four of these six multi-pollutant studies found CV health associations with vehicular emissions, but none of the studies utilized exposure measurements known to reflect subject exposure reasonably accurately, because all used pollution measurements from central monitors as a proxy for personal exposure. While these studies, taken as a whole, suggest the importance of vehicular emissions for the health endpoints examined, strength of effects may be underestimated (Ito et al. 2004), and results are not always consistent. Thus, the most credible studies linking spatially variable vehicular emissions to various health effect endpoints would be those which demonstrate that the ambient pollutant concentrations utilized relate reasonably well to actual exposure of populations examined for health effects.

Concentrations of vehicular emissions have been shown to drop by as much as an order of magnitude within 100 m of a major freeway. People living nearby major roadways will be exposed to greater amounts of vehicular emissions such as BC, ultrafine PM, and gaseous emissions, than will those living at a greater distance (Zhu et al. 2002a, b). As a result, the studies first to show large adverse cardiovascular effects clearly and consistently linked to vehicular emis-

sions were "highway proximity studies." These are studies designed to isolate the health risks of living near a major road from the traditional risk factors typically examined in cohort studies.

Conducted first in Western Europe and Canada, and later in the US, highway proximity studies found significantly elevated risks for cardiovascular death or morbidity outcomes and for all-cause mortality, for people living in close proximity (usually 100 m to major roadways or 50 m to a major urban road), compared to those living farther away. Several utilized data from existing cohort studies, adding only the highway proximity variables. In different ways and to different degrees, these studies accounted for socioeconomic and other variables which could confound pollution–health associations. These studies include the following (statistically significant associations are indicated):

- Finkelstein et al. (2004, 2005; all-cause mortality [relative risk, RR=1.18] and circulatory disease mortality [RR = 1.40], respectively);
- Hoek et al. (2002; cardiopulmonary mortality [RR= 1.95]);
- Gehring et al. (2006; cardiopulmonary mortality, RR= 1.70);
- Tonne et al. (2007; acute myocardial infarction [MI], RR=1.04 to 1.06);
- Hoffmann et al. (2007; increased coronary artery calcification: RRs=1.63 and 1.34 for distances of less than 50 m and 51 to 100 m from highways, vs. more than 200 m distant); and
- Hoffman et al. (2006; incidence of coronary heart disease, RR of 1.85).

These RRs can be compared to RRs for all-cause and cardiopulmonary mortality of 1.04 and 1.06 (per $10 \mu g/m^3$ increase in $PM_{2.5}$) found in the American Cancer Society (ACS) study (Pope et al. 2002). Finkelstein et al. (2004) found a significant mortality rate advancement period of 2.5 years associated with residence near a major roadway.

Another method of associating mortality risks with proximity to traffic and highways utilizes different measures of traffic density (e.g., annual vehicle miles per square kilometer in a county, or daily vehicle kilometer within 100 m of a residence) as a proxy for exposure to vehicular emissions. Relevant studies finding significant health associations with traffic density measures include:

- Kan et al. 2008 (incidence of coronary heart disease [CHD]; significant increase in CHD incidence hazard ratio [HR] of 1.32 for those in highest quartile of traffic density vs. lowest quartile, HR of 1.38 for those in second highest quartile vs. lowest quartile);
- Janssen et al. 2002 (hospital admissions for CVD; one interquartile range [IQR] increase in vehicle miles traveled per square mile significantly associated with a 21.2% increase in CVD hospital admissions);
- Lipfert et al. 2006a, b (all-cause mortality; between these two studies, 30 of 33 tests of traffic density measures were significant, in single and multi-pollutant models, with two different ways of stating risks, with RRs centering around 1.16 in Lipfert et al. 2006a[1]); and
- Medina-Ramon et al. 2008 (survival after heart failure; an IQR increase in daily traffic within 100 m of home significantly associated with a mortality HR of 1.12 after adjustment for SES, and with a HR of 1.30 for those living within 50 m of a bus route).

The Medina-Ramon et al. (2008) study found that a measure of traffic density (vehicle km within 100 m of residence) was a stronger predictor of survival time after heart failure than were other measures, such as similar distance to a major roadway. This finding makes intuitive sense—ideally, exposure should be a product of both proximity and of the amount of pollution produced within that proximity. Just as proximity of a residence to a major highway is a better proxy for exposure to traffic emissions than is centrally monitored PM concentrations, traffic density within 100 m of a residence is likely a better proxy than distance of 100 m from a major road. Distance to a bus route was also an important predictor of survival in Medina-Ramon et al. (2008), suggesting the importance of diesel emissions.

Results of Kan et al. (2008) parallel findings of Hoffmann et al. (2006), in that both studies controlled for hypertension, a mechanism by which noise might cause stress and, thus, by which traffic might cause coronary heart disease via noise pollution rather than chemical pollution. As a result, findings associating mortality and morbidity risks to proximity to busy highways and traffic likely can be attributed primarily to chemical pollution rather than to noise.

Using geographic modeling systems to relate individual residences to either traffic emissions concentrations, distance to major roads, or traffic intensity, other studies also found elevated levels of vehicular pollutants to be associated with adverse cardiac-related health outcomes. Examples include:

- Rosenlund et al. (2006; NO_2 modeled to home significantly associated with out-of-hospital deaths, OR of 2.17 for a 5% to 95% increase in NO_2 [in Stockholm, Sweden]);

[1] The traffic density was insignificant only when EC was also included in a multi-pollutant model; in these cases, both variables came close to significance, but traffic density appeared to be the stronger of the two.

GL14 Continued

- Maynard et al. (2007; significant 2.3% increase in all-cause mortality per IQR increase in BC modeled to home);
- Beelen et al. (2008; significant RR of 1.05 for all-cause mortality for a 5% to 95% increase in black smoke); and,
- Nafstad et al. (2004; significant RR of 1.11 for ischemic heart disease mortality associated with a $10 \mu g/m^3$ increase in NO_2 at home [in Oslo, Norway]).

Finally, Peters et al. (2004) found that a first MI was significantly associated with being in traffic 1 h prior to the event (odds ratio 2.92).

What all of these studies have in common is a demonstration that people exposed to the higher levels of traffic emissions found close to major urban roads or freeways, or modeled to their homes, have higher long-term risks for ischemic heart disease, acute MI morbidity and mortality, and all-cause mortality, or increased risks of a first-time MI with short-term exposure to traffic pollution. These studies, with reasonably accurate subject exposure information for traffic emissions, have results which often (but not always) contrast with studies using central monitors.

Several studies noted above also associated BC or its near equivalent, black smoke, with increased morbidity and mortality risks. Hoek et al. (2002) found risks of cardiopulmonary mortality significantly associated with black smoke (local plus background, RR=1.71; background black smoke, RR=1.34), suggesting the greater effects of fresh, local roadway black smoke. Maynard et al. (2007) found that an increase of one IQR (interquartile range) in previous days BC exposure was associated with a significant increase of 2.3% in all-cause mortality in single-pollutant models, and of 2.2% in two pollutant models. Beelen et al. (2008) found significant increases in all-cause and respiratory mortality associated with black smoke and/or NO_2 but not with $PM_{2.5}$ or SO_2. Nafstad et al. (2004) found a $10 \mu g/m^3$ increase in nitrogen oxides at the home to be associated with significant increases in all-cause and ischemic heart disease mortality of 1.08 and 1.11, respectively. Relative risks of cardiopulmonary mortality of 1.57 and of all-cause mortality of 1.17 were related to near-highway NO_2 exposure in Gehring et al. (2006). Rosenlund et al. (2006) found an odds ratio for out-of-hospital death of 2.17 related to NO_2 exposure.

Mechanistic bases for adverse cardiovascular health outcomes from vehicular emissions-derived PM

In order to provide mechanistic plausibility for the epidemiological findings noted above, it would be helpful to have information about specific conditions or biological responses which could lead to these reported health outcomes. Such information can be derived from in vitro and in vivo toxicology studies, as well as from human panel studies using vehicular emissions or ambient air.

Personal monitors would provide better exposure assessment than would a proxy for personal exposure, such as distance of residence from a major road, or modeled exposure at one's home. Although each of these proxies provides far better exposure differentiation than would a central monitor reading applied to all residents in a locality, there will still be differences in daily activity patterns and, thus, exposures, among similarly situated people. For obvious reasons, cohort studies of mortality and of many morbidity outcomes such as hospital admissions for CV disease could not utilize personal monitors. However, for certain short-term morbidity outcomes with fairly high frequencies, such as change in HRV, ST-segment depression, and arrhythmias, the use of personal pollution monitors or their equivalent may be possible.

Oxidative stress

Oxidative stress is a mechanism postulated to be involved in various PM-induced cardiovascular health effects, including chronic heart failure (McMurray et al. 1993), acute heart failure (especially when patients had atrial or ventricular arrhythmia [Charniot et al. 2008]), and atrial fibrillation (AF; Neuman et al. 2007). Kim et al. (2003) found in AF patients that gene expression profiles for reactive oxygen species were upregulated, while those for anti-oxidants were downregulated. Iravanian and Dudley (2006) suggest a unifying hypothesis that there are multiple triggers for oxidative stress and that oxidative stress, whatever the origin, causes AF. Furthermore, AF itself can result in further oxidative stress, creating a positive feedback loop.

Chahine et al. (2007) found that individuals lacking genes protective against oxidative stress (GSTM1 and the short repeat variant of HMOX-1), but not those with such genes, are vulnerable to HRV changes due to pollution exposure. Instillation of urban air particles and inhalation of concentrated ambient air particles caused oxidative stress in the heart in vivo, as well as reduction in HRV (Rhoden et al. 2005); increases in heart oxidant levels were demonstrated by increases in chemiluminescence or TBARS. Oxidant effects were abolished by the anti-oxidant, NAC. When oxidative stress was abolished, HRV returned to normal (Rhoden et al. 2005). Thus, findings of both Chahine et al. (2007) and Rhoden et al. (2005) suggest that reductions in HRV appear to be due to increased oxidative stress. If this is true, then lack of HRV changes may indicate lack of oxidative stress in some to many cases.

GL14 Continued

Given the evidence that oxidative stress can be mechanistically linked to cardiac pathophysiology, we next review studies which find that exposure to vehicular emissions generally, and to diesel emissions specifically, are linked to oxidative stress.

Pereira et al. (2007) found that in vivo exposure to ambient emissions taken adjacent to a busy road in Porto Alegre, Brazil caused oxidative stress and lipid peroxidation in rat lungs. Similarly, Huang et al. (2003) found that $PM_{1.0}$ was more likely to cause lipid peroxidation in human bronchial epithelial cells than either $PM_{1.0-2.5}$ or $PM_{2.5-10}$, and that the components of $PM_{1.0}$ associated with increased lipid peroxidation were organic carbon (OC) and elemental carbon (EC), but not various ions.

A number of studies suggest that diesel emissions, most specifically ultrafine PAH, appear to be associated with increased levels of cellular oxidative stress. As reviewed in Grahame and Schlesinger (2007), a series of studies demonstrated the ability of both diesel emissions and of ambient air in Los Angeles to cause oxidative stress in vitro in bronchial epithelial cells. These effects were highly correlated with organic carbon and PAH content. Briefly, Li et al. (2002a) found that organic diesel emission particles (DEP) caused oxidative stress in vitro (marked by increases in heme oxigenase-1, HO-1), and Li et al. (2002b) found that concentrated emissions from Los Angeles air, collected from near a major freeway, also caused increases in oxidative stress, e.g., in HO-1. Ultrafine (UF) fractions of Los Angeles air stimulated higher production of HO-1 than did larger PM fractions (Li et al. 2003). Production of HO-1 was correlated with the organic and PAH content of the ultrafine PM. Electron microscopy showed these UF particles penetrated into subcellular structures more easily than did larger particles, and damaged mitochondria. Taken together, these in vitro studies of Los Angeles air suggest that the ultrafine fraction of diesel emissions in Los Angeles air, likely including ultrafine BC coated with a mix of organic compounds, appear to be causally related to the increases in oxidative stress also found to be caused by organic DEP.

Findings of oxidative stress were confirmed in vivo, in a study where HO-1 levels in mice exposed to the exhaust of a normally running newer diesel increased significantly vs. filtered air control (McDonald et al. 2004). Furthermore, when a new catalytic trap was retrofitted on the diesel, most of the carbonaceous emissions were reduced by large percentages, BC was entirely oxidized, and the HO-1 levels were no longer elevated.

The panel study of Delfino et al. (2008) used indoor and outdoor monitors at the residences of 29 non-smoking elderly subjects with coronary artery disease living in Los Angeles. Decreased levels of an anti-oxidant enzyme were significantly associated with increased concentrations of BC, primary OC of outdoor origin, NO_2, and ultrafine PM.

Mills et al. (2005) exposed healthy human volunteers to diluted diesel exhaust ($300 \mu g/m^3$) or to filtered air for 1 h in a double-blind, randomized, crossover study. The authors found that inhalation of diesel exhaust impaired the regulation of vascular tone and endogenous fibrinolysis. Net release of "clotbusting" t-PA antigen was significantly reduced 6 h after exposure. The authors postulated that effects might be caused by reduced availability of nitric oxide (NO) in the vasculature due to oxidative stress induced by the ultrafine particle fraction of diesel exhaust, providing a mechanistic link for associations between PM and acute MIs. Consistent with this supposition, previous work has found that the ultrafine fraction of diesel emissions (likely with adsorbed carbonaceous species) causes greater levels of oxidative stress than larger fractions (Li et al. 2002a, b, 2003; Araujo et al. 2008). The results of Mills et al. (2005) suggest one possible explanation for the significant finding of an initial myocardial infarction in 1 h after being in traffic (as a driver or on public transit) noted by Peters et al. (2004), and for increases in cardiovascular mortality linked to traffic emissions on high pollution days (Schwartz 2003).

Because of its potential to be involved in various specific aspects of CV pathophysiology, further discussion of the role of oxidative stress in pollutant-related health outcomes is provided in discussions of individual CV endpoints below.

Alteration in heart rate variability

Many recent studies assess HRV, which refers to alterations in the beat to beat heart rate and is regulated by the autonomic nervous system. While normal sinus rhythm is characterized by regular R–R intervals in the EKG, the heart does normally show some variability from beat to beat, which can be measured by examination of these intervals. HRV changes appear to be predictive of MI for those who have had a previous MI (Tapanainen et al. 2002), or who have chronic congestive heart failure (Bilchick et al. 2002). Schwartz et al. (2005a) found that in those lacking the allele for glutathione-*S*-transferase M1 (*GSTM1*), a component of the cellular defense against oxidative stress, $PM_{2.5}$ effects on HRV (a decrease in high-frequency component, HF) is mediated by reactive oxidant species. Use of statins, which have anti-oxidant effects, eliminated the effects of $PM_{2.5}$ on HRV. Thus, while changes in HRV may be a cause of cardiac mortality, in particular for those who have had a previous MI, it also appears to be another possible sequela of oxidative stress in the heart (Rhoden et al. 2005; Schwartz et al. 2005a), which has broader health implications than change in HRV alone.

Several recent studies with accurate exposure information suggest that either vehicular emissions specifically, or

GL14 Continued

urban emissions generally, are associated with changes in HRV. A literature search was performed to find studies of HRV which used ambient air and human subjects in the US, and which monitored for at least two of the three pollutants ($PM_{2.5}$, BC, sulfate).

Adar et al. (2007) used a mobile monitor, which followed 44 non-smoking elderly residents of a seniors' home who were going about daily activities, and found significant associations between increased BC exposure for the entire period and changes in six measures of HRV (see Table 1), for two different time periods, a total of 12 significant associations in 12 tests. When the subject boarded a bus and BC concentrations rose by about an order of magnitude, changes in most HRV measures were similar.

Schwartz et al. (2005b) examined HRV in 27 seniors living in close proximity to a busy urban road in Boston. The monitor, located about 0.5 km distant from the living quarters and also adjacent to the same road, recorded BC and PM concentrations which would mirror concentrations at the residences reasonably well (because of similar close proximity to the major urban road). The investigators found in six of eight tests (four HRV measures, two time frames), that increased BC was significantly associated with changes in different measures of HRV (a seventh test was borderline significant). $PM_{2.5}$ was significantly associated in two of eight tests. When an algorithm was used to remove BC from $PM_{2.5}$ on an hourly basis and thus obtain a measure of what the authors viewed as regional $PM_{2.5}$ without fresh BC and correlated emissions, no associations were found between $PM_{2.5}$ and HRV measures (Fig. 1). These findings appear to show that previous studies which did not monitor for BC and found associations with $PM_{2.5}$, may have been detecting unmeasured BC (i.e., vehicular) effects, and that $PM_{2.5}$ was associated with various changes in HRV only when $PM_{2.5}$ was highly correlated with BC, another finding of Schwartz et al. (2005b).

Creason et al. (2001), in a study of 56 non-smoking seniors with a mean age of 82, used wind trajectories to determine which air masses (containing different types of pollution) were associated with changes in HRV. The authors initially found a "U-shaped" association between increasing $PM_{2.5}$ levels and decreasing HRV—as PM concentrations increased from the lowest levels, HRV reductions occurred with increasing $PM_{2.5}$, but toward the highest $PM_{2.5}$ concentrations, HRV reductions reversed, and the HRV measure returned to where it was at the lowest $PM_{2.5}$ levels (null effect). Inclusion of a 2-day air mass with high $PM_{2.5}$ (highest and third highest of 24 days) had caused the reversion. On these 2 days, the investigators found, wind trajectories showed that the air masses had come from rural north-central Pennsylvania. When these 2 days were removed from the analysis, there was a monotonic decrease in HRV with increasing PM, similar to the monotonic decrease in PM found in Schwartz et al. (2005b) when the PM was highly correlated with urban BC. The authors noted that HRV reductions were found when the emissions reflected urban or industrial activity, but that there was no toxicity in the 2 days with high PM from rural areas.

Similar effects were noted by Park et al. (2007), a study of 487 male veterans. The authors found that trajectories reflecting urban emissions (either a stagnant local air mass in Boston or an air mass transported from the Washington, DC through New York City corridor) were associated with changes in several HRV measures. Two other trajectories reflecting mostly rural air masses were not so associated, even though monitored levels of sulfate, BC, and $PM_{2.5}$ were very similar among the air masses. Finally, Ebelt et al. (2005) used personal monitors in a panel study of 16 non-smoking COPD patients, and found that local urban particles, but not sulfates, were associated with HRV changes.

All these above-studies are characterized by reasonably accurate exposure information, whether for BC (Adar et al. 2007; Schwartz et al. 2005b), for PM in urban/industrial air masses vs. rural air masses (Creason et al. 2001; Park et al. 2007) or for urban emissions vs. sulfate (Ebelt et al. 2005). The two studies which monitored for BC (Adar et al. 2007; Schwartz et al. 2005b) showed consistently significant associations between changes in HRV measures and BC concentrations, with virtually no insignificant associations. Further, HRV changes were essentially monotonic with increasing BC levels in these studies.

Since the main contributor to "urban excess" $PM_{2.5}$ is vehicular emissions marked by carbonaceous species (Rao et al. 2002), the urban vs. rural air mass results are consistent with results of exposure to higher BC and vehicular emissions in an urban area. Furthermore, Anselme et al. (2007) exposed Wistar rats (ten healthy, ten with chronic ischemic heart failure, CHF) to diluted diesel emissions. Immediate decreases in a HRV measure (RMSSD) were observed in both healthy and CHF rats following exposure, a finding which parallels the reductions in HRV found in Schwartz et al. (2005b) and Adar et al. (2007) in association with increased BC exposure.

Other extant studies lacking accurate exposure information for locally variable emissions because they used central monitor readings for subjects living over a wide area, generally showed weak (Wheeler et al. 2006; Park et al. 2005) or non-existent (Luttmann-Gibson et al. 2006) associations for locally variable BC (Table 1), while some studies with central monitor readings still found associations with vehicular emissions (de Hartog et al. 2009). The exposure assessment for Luttmann-Gibson et al. in particular, uses a monitor several hundred feet in the air, adding

GL14 Continued

Table 1 Vehicular emissions and heart rate variability changes

Study	Subject exposure method	Characterization of HRV changes	BC levels
A. In vivo animal study			
1. Anselme et al. (2007)	Healthy and CHF rats exposed to diesel emissions	Immediate decrease in RMSSD in both CHF and healthy rats immediately after exposure, returning to baseline after 2.5 h	BC not measured
B. Human studies with accurate exposure			
1. Schwartz et al. (2005b)	Subjects lived adjacent to same urban road to which monitor was adjacent, less than 1 km distant	Monotonic decrease in SDNN with increase in BC exposure; significant BC associations in seven of eight tests (SDNN, RMSSD, PNN50, LF/HF, 1 and 24-h averages); no significant associations in eight tests for $PM_{2.5}$ without BC ("non-traffic secondary particles")	BC mean=1.2 μg/m³
2. Adar et al. (2007)	Monitor followed subjects during activities, in residence at night	For change of one IQR, BC significantly associated with changes in all six measures of HRV, for both 5-min and 24-h means; sharply increased exposure to BC when subjects on buses associated with changes of similar magnitude in all six HRV measures (decreases in SDNN, PNN50+1, RMSSD, LF, and HF; increase in LF/HF), similar to Schwartz et al. (2005b)	BC mean not given; BC IQR for all periods was 330 ng/m³; for bus periods, IQR was 2911 ng/m³
3. Riediker et al. (2004b)	Presence of young patrol officers in vehicle for 9 h before tests	Significant increases in SDNN, PNN50 associated with "speed change" source factor, (braking and diesel emissions), but not "crustal," "steel wear" or gasoline factors	BC not measured
4. Ebelt et al. (2005)	Personal monitors in panel study in Vancouver	Estimated non-sulfate urban $PM_{2.5}$ associated with decreased RMMSD, sulfate not associated	BC not measured
C. Human studies using central monitors not far from street level (horizontal exposure misclassification)			
1. Wheeler et al. (2006)	Central monitor for greater Atlanta area subjects	BC associated with SDNN changes in only one of four tests, NO_2 in only 4 of 13 tests; authors discuss exposure error due to spatial variability of NO_2, note "this greater exposure error is consistent with the fact that traffic, which varies spatially over short distances, is a significant source of outdoor NO_2."	BC mean=1.6μg/m³
2. Park et al. (2005)	Central monitor for subjects living within 40 km of monitor	BC associated with one of four measures of HRV changes; exposure discussed in context of $PM_{2.5}$ (little exposure error) but not discussed for BC	BC mean=0.92μg/m³

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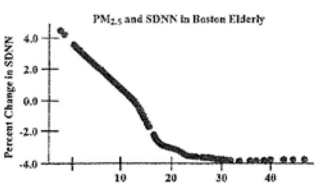
Table 1 (continued)

Study	Subject exposure method	Characterization of HRV changes	BC levels
D. Studies using highly elevated central monitors (horizontal and vertical exposure misclassification)			
1. Luttmann-Gibson et al. (2006)	Central monitor elevated 400 feet above town where subjects lived, a mile from monitor	For IQR change in $PM_{2.5}$ or sulfate, significant reductions in SDNN, RMSSD, HF, and LF (sulfate borderline for LF), no associations for BC; exposure error not discussed	BC mean=1.0 μg/m³

SDNN standard deviation of normal-to-normal intervals, *RMSSD* square root of mean squared difference between adjacent normal-to-normal intervals, *PNN50* percentage of adjacent normal-to-normal intervals differing by more than 50 ms, *HF* high-frequency power, *LF* low frequency power, *LF/HF* ratio LF to HF, *RR* risk ratio, *OR* odds ratio, *IQR* interquartile range increase, *SD* standard deviation

substantial vertical exposure misclassification (Restrepo et al. 2004) to the horizontal exposure misclassification (Ito et al. 2004) found in Wheeler et al. (2006) and Park et al. (2005). We are unaware of any study with reasonably accurate exposure information for BC or for urban emissions which fails to find associations between such emissions and HRV alteration when the latter was examined. A detailed review of US HRV studies utilizing ambient air and human subjects concludes that results of these studies appear to vary consistently with accuracy of exposure to vehicular emissions (Grahame 2009), with consistently strong BC associations with changes in various measures of HRV, almost always significant, only when BC exposure measures are reasonably accurate.

In a study of 643 healthy men and women aged 55 to 75 and with no prior history of heart disease or stroke,



Smoothed plot of the percentage deviation from predicted SDNN (based on the model with all other covariates) versus $PM_{2.5}$ concentrations in Boston. The association flattens out at high concentrations where the correlation between $PM_{2.5}$ and black carbon disappears. (Wording in original).

Fig. 1 SDNN monotonically decreases with increased $PM_{2.5}$ when $PM_{2.5}$ is highly correlated with BC, but is not affected by rising levels of $PM_{2.5}$ when $PM_{2.5}$ is higher and correlated with regional PM, but not BC [from Schwartz et al. (2005b), reproduced with permission]

Sajadieh et al. (2004) suggested the possibility of interactions between HRV changes (imbalance in sympathetic system) and subclinical inflammatory processes in promoting atherosclerosis. Thus, there are likely linkages between various aspects of cardiopulmonary pathophysiology related to pollutant exposure.

ST-segment changes

The ST interval in the EKG represents the period during which the ventricles depolarize. A depression in the ST-segment is associated with increased risk for future cardiac events; those with undetected ST-segment depression have significantly greater risk of death from cardiovascular disease and stroke (Kurl et al. 2003). Pekkanen et al. (2002) found elevated levels of $PM_{2.5}$ mass in urban areas to be associated with ST-segment depression, but could not determine which specific components of $PM_{2.5}$ resulted in such a response. On the other hand, Gold et al. (2005), in a study with the same reasonably accurate exposure protocol as its companion study (Schwartz et al. 2005b), found BC strongly associated with ST-segment depression. Total $PM_{2.5}$, which would include a mixture of both regional and local pollution, was not associated with ST-segment depression in this study.[2] Lanki et al. (2006) found that of several local and regional pollutants, only a traffic factor marked by absorbance coefficient (ABS, similar to black carbon) was associated with ST-segment depression. Subject exposure in Lanki et al. (2006), however, was based on central monitor readings.

[2] Another vehicular emission, CO, was also so associated, but in a two pollutant model with BC was no longer significant. In studies from the 1970s and 1980s, CO was found to be significantly associated with various health endpoints, but CO levels were more than an order of magnitude higher in the 1970s than they are today.

Although Lanki et al. (2006) did not have as accurate exposure characterization as did Gold et al. (2005), both of these studies came to the same conclusion, namely, that vehicular emissions marked by BC or ABS were associated with ST-segment depression. This endpoint, as well as HRV/oxidative stress in the heart and arrhythmias, is among the likely causes for a first-time MI 1 h after being in traffic (Peters et al. 2004).

In a double-blind, random crossover study (Mills et al. 2007), subjects with coronary heart disease were exposed for 1 h to diluted diesel exhaust or filtered air (alternating 15 min of mild exercise with 15 min of rest). ST-segment depression occurred in both sets of subjects, but the average change in ST-segment depression was twice as great in subjects exposed to diluted diesel exhaust. This result with diesel emissions parallels results of the two epidemiological studies of this endpoint reviewed above, which found associations with BC or its equivalent, ABS.

Yan et al. (2008) examined left ventricular function in healthy rats exposed to diesel exhaust particles (NIST standard) and in those subjected to isoproterenol-induced injury as a model for congestive heart failure. Diesel exhaust particles impaired left ventricular functioning, such as end diastolic diameter, in healthy mice, and this was further impaired in the myocardial injured animals. This suggests that acute exposure to these particles may result in exacerbation of congestive heart failure, which supports epidemiological findings of an association between PM components, fine PM, OC, and EC, and hospital admissions for congestive heart failure (e.g., Metzger et al. 2004).

Cardiac arrhythmia

Although some studies have associated measures of air pollution with arrhythmias monitored by implantable cardioverter-defibrillators (ICDs), none to date have utilized either personal pollution monitors or ambient monitors which follow residents of a seniors' home, or the specific exposure protocol of Schwartz et al. (2005b) and Gold et al. (2005). Thus, the available database having good spatial exposure information, and which would also allow evaluation of those pollutants that may be important for triggering arrhythmias, is limited.

Albert et al. (2007) examined risks of an ICD shock during and after driving, finding increased risk in the hour after driving (significant RR=2.24). The risks were specific for ventricular tachycardia or ventricular fibrillation (VT/VF), which occurred primarily in the half hour after driving (RR=4.46, CI=2.92 to 6.82). These risks are similar to but higher than the risks for a first MI found by Peters et al (2004) in the first hour after being in traffic (odds ratio 2.92; 95% CI=2.22 to 3.83). Chamiot et al. (2008) found that oxidative stress in the heart was linked to acute heart failure when a subject had a ventricular arrhythmia. Thus, ventricular arrhythmias and oxidative stress, both of which are linked to exposure to vehicular emissions, together appear to contribute to acute heart failure. However, the role of oxidative stress as a specific cause of such arrhythmias is not yet fully understood. If oxidative stress were to be the cause of VT/VF, then the studies linking BC to HRV/oxidative stress (e.g., Schwartz et al. 2005b; Adar et al. 2007) would point to BC as a primary cause of arrhythmias as well. The actual cause of the oxidative stress could be BC itself, emissions adsorbed onto the BC, and/or emissions highly correlated with BC.

Riediker et al. (2004a, b) examined 11 different health endpoints, including changes in supraventricular ectopic (SVE) beats, an arrhythmia variable, in healthy young patrol officers. Measurements for this endpoint took place 10 h after a 9-h duty shift on roads and highways. Using the suite of emissions measured, the authors established three different factors of emissions, reflecting PM on road surfaces, gasoline emissions, and a "speed change" factor reflecting accelerating diesels and brake wear. Increases in SVE beats were associated only with the speed-change factor.

Ebelt et al. (2005) also found, in a study using personal monitors, increases in SVE beats associated with ambient urban PM and ambient non-sulfate PM, but not with sulfate, in a panel study in the Vancouver area. Table 2 shows results of studies of vehicular emissions and arrhythmias, stratified as in Table 1 by accuracy of exposure.

Peters et al. (2000) examined the incidence of arrhythmias among 100 patients in eastern Massachusetts in relation to various air pollutants (PM_{10}, $PM_{2.5}$, BC, NO_2, SO_2, CO, O_3) measured in South Boston. Associations were found with $PM_{2.5}$, BC, CO, and NO_2 with a 2-day lag. The strongest associations were found for BC and NO_2, which the authors took as evidence of effects of local traffic. However, because of exposure misclassification, BC and NO_2 effects were likely underestimated, a possibility suggested by others (Zeger et al. 2000; Ito et al. 2004) and discussed by authors of several studies with exposure error (Tables 1 and 2). As Peters et al. (2000) noted, "…we would expect any exposure misclassification [for a centrally monitored emission] to…bias the estimates toward the null."

Dockery et al. (2005) followed 203 cardiac patients with implanted ICDs living in metropolitan Boston for an average of 3.1 years each between 1993 and 2002. Pollution ($PM_{2.5}$, BC, SO_4, particle number, NO_2, CO, SO_2, O_3) was monitored at several sites in the metropolitan area. Average concentrations were derived for pollutants with multiple measurements. No significant associations for ventricular tachyarrhythmias were found for an interquartile range increase in any pollutant, for a 2-day pollution mean. However, when stratifying by a recent arrhythmia, significant associations were found for $PM_{2.5}$, BC, NO_2, CO and

GL14 Continued

Table 2 Vehicular emissions and arrhythmia risks

Study	Subject exposure method	Risks of arrhythmia
A. In vivo animal study		
1. Anselme et al. (2007)	CHF rats exposed to diesel emissions; no effect in healthy rats	200% to 500% increase in ventricular premature beats, persisting up to 5 h after exposure
B. Human studies with accurate exposure		
1. Albert et al. (2007)	Presence in vehicle before ICD events	RR of ICD shock in hour after driving =2.24; RR of ventricular tachycardia or ventricular fibrillation in half hour after driving =4.46
2. Riediker et al. (2004b)	Presence of young patrol officers in vehicle for 9 h before tests	~ 40% increase in SVE beats per change of one SD in "speed change" source factor (braking and diesel emissions), but not in "crustal," "steel wear" or "gasoline" factors
3. Ebelt et al. (2005)	Personal monitors in panel study in Vancouver area	Ambient and estimated $PM_{2.5}$, non-sulfate $PM_{2.5}$ each associated with ~ln 0.2 SVE effect estimate; sulfate not associated[a]
C. Human studies using central monitors not far from street level (horizontal exposure misclassification)		
1. Peters et al. (2000)	Central monitor for eastern Massachusetts area subjects	Risks highest for NO_2 and BC, then $PM_{2.5}$; results seen by authors as related predominantly to traffic emissions; OR of ICD shock 2 days later =1.8 for 26 ppb increase in NO_2; due to single monitor, authors' expectation would have been to bias estimates of gaseous emissions toward null
2. Dockery et al. (2005)	Central monitor for subjects living within 40 km of monitor in Boston	Ventricular tachyarrhythmias associated with BC, NO_2, CO, and $PM_{2.5}$, for those with an arrhythmia in previous 3 days, authors see these as indicative of vehicular emissions; for BC, OR=1.74 for increase of 0.74 μg/m³ IQR exposure, for NO_2, OR=1.34 for 7.7 ppb IQR increase; exposure misclassification discussed, thought to weaken associations observed
3. Metzger et al. (2007)	Central monitor data for patients living in metro Atlanta area	No associations with ICD events with $PM_{2.5}$, NO_2, CO, EC, OC, SO_4; exposure misclassification discussed, study "does not contribute evidence regarding whether personal exposure may be a determinant of ventricular tachyarrhythmia"
4. Rich et al. (2006)	Central monitor for subjects living within 40 km of monitor in Boston	No risk associations for paroxysmal atrial fibrillation episodes with $PM_{2.5}$, NO_2, BC, CO, or SO_2; associations only with ozone; small number of episodes, thus reduced statistical power discussed, but exposure misclassification not discussed
D. Studies using highly elevated central monitors (horizontal and vertical exposure misclassification)		
1. Sarnat et al. (2006)	Central monitor elevated 400 feet above town where subjects lived, a mile from monitor	For 5-day moving average in pollution concentration, OR for having an SVE=1.42 for $PM_{2.5}$; 1.70 for sulfate; no associations for BC

RR risk ratio; *OR* odds ratio; *IQR* interquartile range increase; *ICD* implantable cardioverter-defibrillators; *SVE* supraventricular ectopy; *SD* standard deviation

[a] Association taken from Fig. 2 in Ebelt et al. (2005). Association in Ebelt et al. also reported [in Sarnat et al. (2006)] as a 22% increase in rate of SVE for subjects whose mean rate of SVE was 33 bph

GL14 Continued

SO_2, and a borderline significant association for SO_4, for an interquartile increase in the 2-day pollution mean; this finding suggests that the most at-risk patients in general may also be most at risk for a pollution-related ventricular tachyarrhythmia. The authors took the associations with $PM_{2.5}$, CO, NO_2, and BC as indicative of a link with motor vehicle emissions, and the sulfate association as evidence of a link with regional fossil fuel emissions. SO_2 was highly correlated with vehicular emissions and was seen as local in origin. In light of the findings of Albert et al. (2007), the lack of an association in this study with particle number, which is considerably higher in the 100 m nearest a major road (Zhu et al. 2002a, b), suggests that exposure misclassification may also have occurred in this study, perhaps understating effects of local vehicular emissions and transferring health associations to other emissions (Goldberg and Burnett 2003). The authors note that "… improved estimate of subject specific air pollution exposures would be expected to find stronger, more statistically significant associations."

Another study having exposure misclassification is that of Metzger et al. (2007), conducted in the Atlanta area and involving 518 patients with ICDs; there were found to be no associations with tachyarrhythmias for any of the emissions monitored (PM_{10}, ozone, NO_2, CO, and SO_2 for 10 years, $PM_{2.5}$ and oxygenated hydrocarbons for 4 years). Metzger et al. also discussed exposure misclassification, stating that the study "does not contribute evidence regarding whether personal exposure may be a determinant of ventricular tachyarrhythmia."

Sarnat et al. (2006) examined pollutant associations with supraventricular and ventricular arrhythmias. This was a companion study to that of Luttmann-Gibson et al. (2006), who examined pollution associations with reduced HRV in Steubenville, Ohio during summer and fall 2000. Both studies used a monitor several hundred feet higher than the living quarters of the subjects, and about a mile distant. Like Luttmann-Gibson et al., Sarnat et al. found associations with sulfate, but not with BC, although the companion study also found associations with $PM_{2.5}$. Exposure misclassification for locally variable emissions such as BC is particularly severe, as with the companion study, due to the monitor's height.

Anselme et al. (2007) found an immediate 200% to 500% increase in ventricular premature beats in CHF rats compared to healthy rats exposed to diluted diesel emissions. This finding is similar that of Dockery et al. (2005), in which the significant pollution associations for ventricular arrhythmias were only for those who had had a previous arrhythmia in the previous 3 days vs. more healthy people. The increase in arrhythmias following exposure to diesel exhaust in Anselme et al. (2007) appears to have its strongest parallels in the findings of Albert et al. (2007), e.g., increases in VT/VF in subjects half an hour after being in traffic, and of Riediker et al. (2004a, b), which found that the "speed change" factor, marked by diesel emissions and brake wear, was associated with significant increases of about 40% in SVE beats. Of the four epidemiological studies, none of which had good exposure information for spatially variable local vehicular emissions, two nevertheless suggest that traffic emissions are associated with arrhythmias, and three discussed exposure misclassification as a possible reason for results being smaller and weaker than had exposure information been more accurate.

The rapid initiation of arrhythmias after exposure to diesel emissions may suggest a direct effect on the myocardium. Anselme et al. (2007) state that such a quick response supports the idea that agents such as ultrafines, gasses, or soluble PM do cross the pulmonary epithelium into the circulation. However, rapid initiation might instead support the findings of Rhoden et al. (2005), who found that antagonists of both the sympathetic and parasympathetic nervous systems prevented oxidative stress in the heart caused by instillation of urban PM or inhalation of CAPs. In this second case, it might not be necessary for pollution to enter the bloodstream; oxidative stress in the heart due to exposure to PM (Rhoden et al.) or diesel emissions (Anselme et al.) might cause arrhythmias via direct modulation of the vagal nerve.

Inflammation

Initiation of an inflammatory response is another potential mechanism underlying PM-induced cardiovascular effects. Ridker et al. (2008) demonstrated that reducing systemic inflammation, initially marked by levels of high-sensitivity C-reactive protein (CRP), resulted in significant reduction of cardiovascular events (MI; revascularization or unstable angine; stroke; combined end point of MI, stroke, and death from any cardiovascular cause; and death from any cause) among those with low LDL cholesterol levels (<130 mg/dL) but initially high CRP (>2.0 mg/L). CRP itself is not the cause of progression of disease, however, but rather an indicator of inflammation (Schunkert and Samani 2008). Thus, elevated chronic systemic inflammation appears to be a cause of increased cardiovascular mortality and morbidity, even among apparently healthy people without hyperlipidemia. Systemic inflammation as marked by interleukin-6 (IL-6) is also associated with higher risks of mortality among older female CVD patients (Volpato et al. 2001) and with higher risks of a future MI among apparently healthy men (Ridker at al. 2000).

Bonvallot et al. (2001) exposed human bronchial epithelial cells to DEP and to DEP organic extracts, both of which induced activation of pro-inflammatory NF-κB, but the stripped carbonaceous core induced less intense

GL14 Continued

responses. NF-κB is involved in inducement of inflammatory cytokines such as TNF-α, IL-6, and IL-8. Bonvallot et al. showed that DEP induced expression of a cytochrome P-450 specifically involved in PAH metabolism. This finding suggests the importance of PAH organic compounds in diesel emissions in causing inflammatory responses.

McDonald et al. (2004) found that diesel emissions from a relatively new diesel engine operating in steady state caused significant increases in several biological endpoints in mice, including inflammatory cytokines IL-6, TNF-α, and INF-γ (as well as oxidative stress, as marked by HO-1), with exposures of 200 μg/m^3 (6 h/day, 7 days). Use of a catalyzing trap eliminated virtually all the black carbon and a large percentage of many carbonaceous emissions, and also abolished the significant increases in cytokines and HO-1.

Tornquist et al. (2007) exposed 15 healthy men to diesel exhaust or filtered air for 1 h. In those exposed to diesel emissions, there were significant increases in TNF-α and IL-6, paralleling in vitro and in vivo findings just reviewed.

Seaton et al. (1999) estimated exposure to PM_{10} in 108 elderly subjects in Belfast and Edinburgh, modeling estimated personal exposures based upon activity diaries and multiple monitoring sites. Increased CRP was significantly associated with city center measurements of PM_{10}, but IL-6 was not. Another European multi-city study (Ruckerl et al. 2007) found in pooled results a significant increase in IL-6 per interquartile range increase (IQR) of particle number count 12–17 h before blood withdrawal, and per same day IQR increase in NO_2 (primarily a marker for vehicular emissions in European cities); no such association was found with CRP.

Riediker et al. (2004a), Riediker (2007), and Delfino et al. (2008) are examples of studies with excellent exposure assessments. Both of the Riediker et al. studies examined effects of 9 h of exposure to in-vehicle pollution on various cardiovascular parameters in healthy young male patrol officers. In Riediker et al. (2004a), elevated CRP was significantly associated with in-vehicle $PM_{2.5}$, but not with roadside $PM_{2.5}$. In Riediker (2007), IL-6 levels were significantly increased by about 20% for a one-standard-deviation increase in in-vehicle $PM_{2.5}$. Although IL-6 was not measured in the 2004 study, and CRP was not measured in the 2007 study, we can reasonably conclude that both CRP and IL-6 are elevated when healthy young men are exposed to several hours of vehicular emissions at levels found inside on-road vehicles.

Delfino et al. (2008) examined biomarkers of inflammation, anti-oxidant activity, and platelet activation in a panel study of 29 non-smoking elderly with CHD in retirement homes in Los Angeles. Using monitors just outside and inside the residences, the authors modeled concentrations of outdoor emissions inside the homes, where subjects spent most of their time. Delfino et al. (2008) found that several biomarkers of inflammation (CRP, IL-6, and soluble receptor-II for TNF-α) increased significantly with increasing exposure to various vehicular emissions (current day and multi-day averages). Reduced anti-oxidant activity was found for all but three subjects with several different traffic emissions. Among PM size fractions, only the smallest particles ("quasi-ultrafines," $PM_{0.25}$) were significantly associated with these biomarkers, paralleling findings regarding particles in Los Angeles taken close to freeways with regard to oxidative stress, as reviewed above. Particle number, BC, EC, CO, and primary OC were also associated with one or more of the biomarkers. Interestingly, secondary organic carbon showed no associations.

Thus, three studies of humans exposed to ambient air with accurate exposure monitoring found elevated levels of inflammatory indicators CRP and IL-6 associated with increased in-vehicle $PM_{2.5}$, or with several vehicular emissions. Of the other two studies (Seaton et al. 1999 and Ruckerl et al. 2007), one found elevated CRP in subjects in relation to modeled central city PM_{10}, while the other found IL-6 was elevated relative to centrally monitored particle number and NO_2 concentrations. Tornquist et al. (2007) found in healthy human volunteers significant increases in IL-6, TNF-α, and soluble P-selectin 24 h after inhalation (1 h) of 300 μg/m^3 diesel exhaust, suggesting the role of diesel emissions in the epidemiological findings noted above. Findings of these studies are in concert with the in vitro (Bonvallot et al. 2001) and in vivo (McDonald et al. 2004) studies reviewed above as well. Bonvallot et al. establishes a possible biological mechanism of inflammation involving PAHs.

Zeka et al. (2006) studied 710 members of the VA Normative Aging Study cohort living in the greater Boston area, with air pollution measured at a central monitor. Despite the potential exposure misclassification, the authors found an association for elevated CRP with an increase in one standard deviation in BC (for those with a BMI over 30, e.g., obese). Risks of elevated CRP were approximately four times higher for obese than for non-obese. Significant associations were not found for CRP with other types of PM. Those lacking a measure of genetic protection against oxidative stress, e.g., *GSTM1*-null subjects, were significantly more likely to have increased levels of CRP associated with increased BC concentrations. The authors discuss exposure misclassification, noting that a limitation of the study was the inability to measure personal exposure to different types of PM, and that they "would expect an underestimation of the effects of air pollution observed in the present study."

Atherosclerosis

Atherosclerosis refers to a thickening of the luminal wall of arteries that, depending upon the specific type of condition,

GL14 Continued

may or may not result in reduction in blood flow. Atherosclerosis may be considered an inflammatory disease which progresses in concert with oxidation of LDL lipids (Steinberg 2002). Thus, initiation or exacerbation of inflammation, associated with pollutant exposure, may be a mechanism for some of the health outcomes noted herein.

Studies reviewed above show links between vehicular emissions and acute HRV reductions/oxidative stress reactions. A study of 1,133 non-smokers in a Swiss cohort (Probst-Hensch et al. 2008) found that those with glutathione-*S*-transferase polymorphism deletions (which reduce anti-oxidant defenses) have altered autonomic control, as marked by reduced HRV. The authors conclude that their results are consistent with an important pathological role for systemic, chronic oxidative stress among the general population. Although unexplored in this study, these findings may suggest as well that vehicular emissions which cause acute oxidative stress and thus change in HRV may be causally related to increases in arterial plaque formation via oxidation of LDL cholesterol. In this regard, Romieu et al. (2008) examined residents of a Mexico City nursing home for 6.5 months. Mexico City's elevated pollution levels contain high levels of vehicular emissions, likely resulting in increased oxidative stress. Subjects were treated with anti-oxidants (fish oil and soy oil supplements). Both supplements increased antioxidant activity, as measured by biomarkers of response to oxidative stimuli [glutathione (GSH) and Cu/Zn superoxide dismutase (SOD) activity]. Those treated with fish oil supplements, but not soy oil, also had 72% less lipoperoxidation. These results suggest that chronic oxidative stress caused by urban pollution is linked to increased lipoperoxidation, likely enhancing development of atherosclerotic plaques.

In the panel study of elderly non-smoking subjects reviewed above, Delfino et al. (2008) also examined associations of platelet activation, marked by soluble P-selectin, with various emissions. P-selectin is an adhesion molecule which plays an important role in atherosclerosis via leukocyte recruitment (Woollard and Chin-Dusting 2007). Delfino et al. (2008) found increased levels of soluble P-selectin significantly associated with increased levels of EC of outdoor origin and primary OC, suggesting that these emissions can produce platelet activation and, thus, advance atherosclerosis.

Araujo et al. (2008) showed that inhalation of concentrated ultrafine PM from close to a Los Angeles freeway, enriched in PAHs, caused significantly larger early atherosclerotic lesions in genetically susceptible (apolipoprotein E-deficient) mice inhaling concentrated $PM_{2.5}$ or filtered air. Exposure to ultrafine PM also resulted in inhibition of anti-inflammatory capacity of plasma HDL and greater systemic oxidative stress, in part as evidenced by upregulation of Nrf2-regulated anti-oxidant genes. The atherosclerotic lesions were likely caused by the combination of oxidative stress and inflammation, as both appear to be necessary for development of atherosclerosis (Steinberg 2002).

Studies reviewed noted above found ambient levels of traffic emissions PM to be associated with both oxidative stress and inflammation. Findings of Araujo et al. (2008), with a sensitive murine model, are in concert with both the findings of Delfino et al. (2008) and the epidemiological results of Kuenzli et al. (2005), i.e., that people exposed to higher annual levels of ambient air in Los Angeles had higher prevalence of atherosclerotic plaque or of important precursors of such plaque. The results of Araujo et al. (2008) are also consistent with the findings of Romieu et al. (2008), who found that lipoperoxidation in residents of a highly polluted city was reduced by use of a common anti-oxidant. Findings of these studies are also consistent with findings of studies in the sections on oxidative stress and inflammation, with regard to exposure to diesel emissions, urban pollution, and specific emissions such as BC.

Gong et al. (2007) examined exposure to ambient ultrafine particles that were highly enriched in redox cycling organic chemicals in terms of promotion of atherosclerosis in mice. The investigators found that an interaction between diesel exhaust particles and oxidized LDL lipids synergistically affected gene expression corresponding to pathways relevant to vascular inflammatory processes such as atherosclerosis. This study suggests how the lipid peroxidation found in the Huang et al. (2003) and Pereira et al. (2007) studies could lead to atherosclerosis such as found by Kuenzli et al. (2005) and lipoperoxidation as noted by Romieu et al. (2008). Similarly, Sharman et al. (2002) found that people regularly occupationally exposed to vehicular emissions (auto mechanics) had greater plasma susceptibility to oxidation, and, thus, a greater risk of developing atherosclerosis than did matched controls.

Kuenzli et al. (2005) and Jerrett et al. (2005) utilized a modeled $PM_{2.5}$ "surface" created for Los Angeles by interpolating data from 23 fixed-site monitors, creating within-city gradients for exposure to $PM_{2.5}$. Motor vehicles are the major source of emissions in Los Angeles, since other potentially major stationary sources of pollution (e.g., coal-fired power plants, steel mills, and coke industries) are absent. Thus, $PM_{2.5}$ in the Los Angeles basin as a whole is related primarily to vehicular emissions, although near ports shipping emissions may also be important.

Using the ACS data base for Los Angeles, Jerrett et al. (2005) found the relative risks for all-cause and cardiovascular mortality three to four times larger than in the original ACS study, which examined inter-city differences in $PM_{2.5}$, vs. intracity differences. Kuenzli et al. (2005) found higher levels of $PM_{2.5}$ within the Los Angeles airshed to be associated with higher levels of atherosclerotic plaques in

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the carotid artery (associations were strongest for women 60 years old or older.) These results, suggesting that mainly vehicular-derived $PM_{2.5}$ in Los Angeles may be causally related to the development of atherosclerosis, parallel those of Hoffmann et al. (2007), noted above, who found that people living close to major roads had significantly higher levels of coronary atherosclerosis as measured by coronary artery calcification.

Vascular function and blood pressure

Another potential mechanism by which vehicular-derived PM could cause cardiovascular injury involves changes in vascular tone. Urch et al. (2004, 2005) exposed healthy human volunteers to ozone plus CAPs (concentrated ambient particles) obtained in close proximity to a major Toronto freeway. The resultant increase in vasoconstriction of the brachial artery (2004 study) was associated with EC and OC, but not with any of the other 23 components of $PM_{2.5}$ examined, suggesting traffic emissions as a likely causal source. Diastolic blood pressure (2005 study), possibly related to the vasoconstriction findings of the first study, increased with increased levels of organic carbon and was attributed to traffic emissions.

Miller et al. (2009) exposed rat aortic rings in vitro to diesel exhaust particles (DEP) to explore mechanisms of effects on vascular function. The authors found that oxidative stress caused by DEP reduced the bioavailability of endothelium-derived nitric oxide "without prior interaction with the lung or vascular tissue."

Bartoli et al. (2009) examined the effects of CAPs collected adjacent to a major urban road on blood pressure of dogs. Increases in systolic blood pressure (SBP), diastolic BP (DBP), mean BP, heart rate, and rate times pressure were all associated with an IQR increase in $PM_{2.5}$, BC, and particle count, with the size of the effect increasing in that order (BC marginally significant for systolic pressure). As with the studies of Urch et al. the CAPs were taken from next to a major road, exposure was accurately known, and the BC, carbonaceous and/or ultrafine PM (emitted from traffic) were highly associated with the increases in BP.

Subjects in the multi-city study of Auchincloss et al. (2008) were aged 45–84 and clinically free of CVD. The authors found several associations between $PM_{2.5}$ and pulse pressure (PP), with only one model (which included traffic emissions) finding associations with SBP. Further analysis showed that when $PM_{2.5}$ exposure for subjects was stratified by either of three traffic variables (NO_2 levels above median; residence within 300 m of highway; or high density of roads nearby residence), a 10-μg/m^3 increase in $PM_{2.5}$ was associated with increased PP (all three cases) and SPB (two or three cases) when the traffic variable was "positive," but not when the traffic variable was "negative." Thus, $PM_{2.5}$ exposure was not associated with either endpoint unless exposure level to traffic emissions was stratified as "high." Using different methods of assessing exposure to vehicular emissions in a multi-city study, these investigators found similar SBP results to the studies above using CAPs taken from nearby major roads.

Findings have been inconsistent with regard to elevated blood pressure associations among studies lacking reasonably accurate information for exposure to locally variable emissions, such as those from vehicles. Ibald-Mulli et al. (2004) examined 131 subjects with coronary heart disease in three European cities, used centrally monitored $PM_{2.5}$, accumulation mode, and ultrafine particle mass concentrations. Results were controlled for temperature, barometric pressure, and relative humidity. Very small negative, but significant, associations were found for both SBP and DBP with particles of different sizes. However, the authors cautioned against inferring clinical relevance from these findings. Zanobetti et al. (2004), in a study of residents of greater Boston, found positive and significant $PM_{2.5}$ associations (mean level for 5 days before physician visits) with resting SBP, DBP, and mean arterial BP (MAP). In addition, for those with resting heart rate >70 bpm, mean $PM_{2.5}$ level for the 2 days preceding the visit were associated with increases in DBP and MAP during exercise. Temperature, dew-point temperature, and barometric pressure, as well as standard socioeconomic variables, were controlled for. Pollutants were measured at central sites. Associations were found with SO_2, O_3, BC, but not with NO_2 or CO in single-pollutant models, but only $PM_{2.5}$ remained associated with elevated DBP in multi-pollutant models.

Thus, it appears that when exposure to vehicular emissions are reasonably well characterized—as when ambient air is from near a major road, or when results are stratified by whether someone lives near major roads or has a high density of roads near their residence—increased blood pressure effects are consistently found associated with vehicular emissions. However, in the absence of reasonably well-characterized exposure information for vehicular emissions, associations become inconsistent, and vehicle-specific emissions are less likely to be associated with change in blood pressure.

Lai et al. (2005) found that toll workers exposed to traffic exhausts had significantly higher levels of plasma NO, an agent affecting vascular tone, than similar workers not so exposed, suggesting another pathway by which vehicular emissions could adversely influence vascular tone.

Peretz et al. (2008) exposed 27 adult volunteers (ten healthy, 17 with metabolic syndrome) to diluted diesel exhaust (100 or 200 μg/m^3 $PM_{2.5}$) or filtered air. The authors examined brachial arterial diameter change, and

collected systemic blood samples for endothelin-1 (ET-1), a vasoconstrictor. Reduction in brachial artery diameter was linearly related to increasing exposure concentration of the exhaust, paralleling the findings of Urch et al. (2004), which used CAPs from nearby a Toronto freeway, and suggesting the importance of diesel emissions specifically for this endpoint. Plasma levels of ET-1 were increased only at the highest concentration of exposure.

Campen et al. (2005) found that fresh diesel emissions can cause vasoconstriction in the blood vessels of mice ex vivo, but that filtering diesel exhaust to remove particles did not change the vasoconstrictive properties of the emissions. Further analysis suggested that two specific gaseous emissions, aldehydes and alkanes, appeared to be responsible for these effects, suggesting a potential biological mechanism for the findings of Urch et al. (2004, 2005).

Changes in vascular homeostasis may be due to oxidative stress on endothelial cells or to systemic inflammation that affects the endothelium. Peretz et al. (2007) exposed healthy adults to diluted diesel exhaust and used microarray techniques to assess effects in peripheral blood leukocytes, since these cells are involved in inflammation and control of vascular homeostasis, including development of atherogenesis (Kristovich et al. 2004; Libby et al. 2002). They noted that the diesel exhaust exposure preferentially modulated genes involved in oxidative stress, inflammation, leukocyte activation, and vascular homeostasis, mechanisms by which adverse health effects may be modulated.

Research recommendations

Different types of particles have different biological effects, and some are likely to be more harmful than others; for example, some might cause more oxidative stress. Additional effort is needed to move closer to the goal of regulating those specific types of particles and emissions which may have the greatest health relevance. Research recommendations are made with this goal in mind.

First, although we suggest, based upon the data base discussed, that creation of a black carbon PM standard under the National Ambient Air Quality Standards may serve to protect public health, there is still much research to be done with regard to the different components of vehicular emissions. Non-PM carbonaceous components of vehicular emissions have adverse health effects (Mauderly and Chow 2008), but relatively little research has been done to date on them. Even if a black carbon standard were regulated under the NAAQS, and even if as a consequence of such a standard, many VOC and SVOC emissions would be controlled simultaneously, gasoline engines emit many of the same VOCs as diesels, and many different ones as well.

Several toxicology studies of gasoline emissions, using genetically engineered mice, have generated hypotheses about their effects. Lund et al. (2007), in a study using atherosclerosis-prone genetically modified ApoE$^{-/-}$ mice, showed that the gaseous fraction of gasoline emissions were associated with increased markers of vascular oxidative stress and transcriptional upregulation of factors associated with vascular remodeling important to the development of atherosclerosis. Campen et al. (2006), using the same mouse model, found that fresh gasoline emissions, but not paved road dust, altered cardiac repolarization. Should research establish that these emissions also cause serious harm to public health, technology solutions will have to be found for these as well.

More health endpoints appear to have been examined for diesel than for gasoline engine exhaust at this point, especially when using ambient air or human subjects or both; thus, further research is needed. To establish a comprehensive and consistent basis of comparison of gasoline with diesel emissions, ways should be found to test gasoline emissions in protocols using human subjects parallel to those of Mills et al. (2005, 2007), for example.

A second research recommendation is also quite important to determining which emissions need to be controlled to protect public health. It may be reasonable to think that today, there are two widespread types of air pollution of public health concern: those from vehicles and those from power plants, especially those using coal. Two to three decades ago, use of residual oil use was much more widespread than now, and the oil also contained higher amounts of metals (V, Ni) and sulfur (Thurston and Spengler 1985). With less than 3% of electric generation from residual oil today vs. 17% three decades ago, today's residual oil emissions are lower and more localized. Similarly, there were formerly more coking and non-electric arc steel plants, and these plants did not face the emission regulations they face today. Thus, epidemiological studies of the 1970s and 1980s would have had to be attentive to specific emissions from these sources in more locations and on a more regional scale than more recent studies.

Many early studies of PM did not recognize, as we now do, either the importance of monitoring specifically for emissions from vehicles, or the need to have reasonably accurate exposure information for such emissions. Now that methodologies rectifying these deficiencies are available, we recommend they be used to examine whether cardiovascular effects found to be associated with vehicular emissions, as in the studies above, are also found with emissions representing coal emissions (secondary sulfates and coal fly ash) as well as associated products of atmospheric chemistry involving such emissions.

Thus, one recommendation would be to perform tests utilizing ambient air masses, as with the work of Schwartz

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Table 3 Summary of effects of vehicular emissions and black carbon on CVD health endpoints

Health endpoint	In vitro studies	In vivo studies	Human panel studies
1. Oxidative stress	Li et al. 2002a (increases in HO-1, diesel PM)	McDonald et al. 2004 (diesel emissions, increased HO-1 in normal mice; oxidative stress abolished with use of catalyzing trap which totally eliminated black carbon, largely eliminated most organics, including many PAHs)	Mills et al. 2005 (diesel emissions, healthy human volunteers; reduction in t-PA, impairment of vascular tone, postulated by authors to be related to oxidative stress; also see HRV Alteration [HRV changes often caused by oxidative stress])
	Li et al. 2002b (increases in HO-1, Los Angeles air)		Delfino et al. 2008 (decreased levels of anti-oxidant enzyme activity, in panel of 29 non-smoking elderly subjects with history of coronary artery disease associated with BC, NO_2, primary OC of outdoor origin, and ultrafine PM, for current day and multi-day averages, in study with excellent exposure characterization, using both indoor and outdoor monitors at Los Angeles residences)
	Li et al. 2003 (increases in HO-1, most harm caused by ultrafines in Los Angeles air, correlated with organics and PAHs)		
2. HRV alteration	NA	Anselme et al. 2007 (diesel emissions, HRV decreases in healthy and CHF rats immediately after exposure)	Adar et al. 2007 (changes in six different types of HRV associated with BC exposure; when subjects on bus with high BC levels, larger HRV changes roughly correspond with larger changes in BC; monitor followed subjects wherever they went)
			Schwartz et al. 2005b (changes in 4 types of HRV associated with BC concentrations, but not with concentrations of non-BC regional $PM_{2.5}$; subjects live on same road as monitor is located, both in close proximity to road, 0.5 miles apart)
			Creason et al. 2001 (HRV changes monotonically associated with increasing $PM_{2.5}$, after two days with high $PM_{2.5}$ from only rural sources eliminated from regression)
			Ebelt et al. 2005 (HRV associations found for ambient urban PM, not found for sulfate; personal monitors used)
			In studies using central monitors, Wheeler et al. (2006) and Park et al. (2005) show associations with BC in only one fourth of tests; Luttmann-Gibson et al. (2006) find no BC associations.
			Park et al. (2007) is same study as Park et al. (2005), but uses wind trajectories to determine sources, thus has better exposure information than Park et al. (2005); HRV associations found for urban air masses, not for rural air masses

GL14 Continued

Table 3 (continued)

Health endpoint	In vitro studies	In vivo studies	Human panel studies
3. ST-segment Depression	NA	Yan et al. 2008 (diesel exhaust particles impaired left ventricular functioning in healthy rats, with further impairment in rats with myocardial injury)	Mills et al. 2007 (ST-segment depression in subjects with CHD exposed to diesel emissions twice as great as for subjects without CHD, suggesting how diesel emissions could harm susceptible subjects)
			Gold et al. 2005 (in parallel study to Schwartz et al. 2005b HRV study, e.g., with accurate exposure information, ST-segment depression associated with BC but not with $PM_{2.5}$)
			Lanki et al. 2006 (in study of several local and regional pollutants lacking good exposure information, ST-segment depression associated with ABS [EU equivalent of BC] but not with sulfate or other pollutants)
4. Cardiac Arrhythmia	NA	Anselme et al. 2007 (diesel emissions, 200% to 500% increase in ventricular premature beats in CHF rats, but not in normal rats)	Albert et al. 2007 (risks of ICD shock elevated in hour after driving, RR= 2.24; risks for ventricular fibrillation or tachycardia elevated in half hour after driving, RR=4.46)
			Riediker et al. 2004a, b (~40% increase in SVE beats for change of one SD in "speed change" factor reflecting diesel emissions and brake wear)
			Ebelt et al. (2005) (SVE associations found for ambient urban PM, non-sulfate ambient urban PM, not found for sulfate; personal monitors used)
			Peters et al. (2000), Dockery et al. (2005), Metzger et al. (2007), and Sarnat et al. (2006) are extant studies of arrhythmias using central monitor concentrations as proxies for subject exposure over large metropolitan areas, causing exposure misclassification; first study finds larger associations with vehicular emissions (BC and NO_2) than with $PM_{2.5}$; second study finds traffic emissions more likely cause of arrhythmias; third study finds no associations; associations in fourth study are with sulfate but not with BC; the first three studies discuss exposure misclassification as possible reason for underestimates of associations
5. Vascular Function	Miller et al. 2009 (diesel particles reduce bioavailability of endothelium-derived NO in aortic rat rings in vitro via oxidative stress, without prior interaction with lung or vascular tissue)	Bartoli et al. 2009 (increases in mean, systolic and diastolic blood pressure found in dogs exposed to CAPs taken from near major urban roadway; BC, carbonaceous particle count associated with increases in blood pressure)	Urch et al. 2004 (significant increase in vasoconstriction in healthy human volunteers exposed to CAPs taken from near freeway associated only with EC and OC among 25 components of $PM_{2.5}$ analyzed)
	Campen et al. 2005 (fresh diesel emissions and filtered diesel exhaust cause vasoconstriction in mice ex		Urch et al. 2005 (significant increase in blood pressure in healthy human volunteers exposed to CAPs taken

GL14 Continued

Table 3 (continued)

Health endpoint	In vitro studies	In vivo studies	Human panel studies
	vivo, aldehydes and alkanes most likely involved)		from near freeway, possibly associated with increase in vasoconstriction in 2004 study, related to traffic emissions) Auchincloss et al. 2008 (in subjects aged 45–84, systolic blood pressure and pulse pressure associated with increased $PM_{2.5}$ only when traffic variables (NO_2 levels above median value; residence within 300 m of highway; or high density of roads near residence) were "positive," not when traffic variables were "negative") Lai et al. 2005 (toll workers exposed to traffic exhaust had significantly higher levels of plasma NO, which affects vascular tone) Peretz et al. 2007 (in healthy adult volunteers, diesel exhaust preferentially modulated genes involved in oxidative stress, inflammation, leukocyte activation and vascular homeostasis) Peretz et al. 2008 (in adult volunteers exposed to diesel exhaust, reduction in brachial artery diameter linearly related to increasing concentration of exhaust; plasma levels of endothelin-1, a vasoconstrictor, significantly increased only at $200 \mu g/m^3$ of diesel exhaust, but not at $100 \mu g/m^3$)
6. Inflammation	Bonvallot et al. 2001 (diesel emissions and diesel organic extracts induced increased levels of pro-inflammatory NF-κB in human bronchial epithelial cells; less intensive effects induced by stripped carbonaceous core)	McDonald et al. 2004 (increased levels of three inflammatory biomarkers (TNF-α, IL-6, and INF-γ) associated with exposure to diesel emissions, effects abolished with use of new catalyzing trap which eliminated BC completely, largely eliminated most organics, including many PAHs)	Delfino et al. 2008 (several biomarkers for inflammation [CRP, IL-6, TNF-α receptor] significantly increased with increased concentrations of BC, EC, CO, primary OC, and with increased particle number) Riediker et al. 2004a (CRP elevated with increased in-vehicle PM, in study of patrol officers after 9-h shift) Riediker 2007 (IL-6 elevated with increased in-vehicle PM, in study of patrol officers after 9-h shift) Tornquist et al. 2007 (diesel emissions increased TNF-α, IL-6 levels in healthy human volunteers, vs. filtered air) Zeka et al. 2006 (elevated BC levels, recorded at central monitor, associated with increased CRP levels in the obese, and in those lacking a measure of genetic protection against oxidative stress, e.g., GSTM1-null subjects. Authors discuss exposure misclassification, note that they would expect larger risks with better exposure assessment)

GL14 Continued

Table 3 (continued)

Health endpoint	In vitro studies	In vivo studies	Human panel studies
7. Atherosclerosis and lipoperoxidation	See oxidative stress and inflammation sections for in vitro work relevant to atherosclerosis, caused in large part by systemic interaction of oxidative stress and inflammation	Araujo et al. 2008 (increased early atherosclerotic lesions in ApoE $^{-/-}$ mice breathing CAPs ambient in PAHs from near LA freeway, exposure to ultrafine PM inhibited anti- inflammatory capacity of plasma HDL)	Sharman et al. 2002 (auto mechanics, regularly exposed to higher levels of vehicular emissions than controls, had significantly higher susceptibility of plasma to oxidation)
	Gong et al. 2007 (interaction between oxidized LDL lipids and organic diesel emission extracts affects gene expression relevant to vascular inflammation and atherosclerotic pathways in human microvascular endothelial cells; work then replicated in vivo, with similar findings – see in vivo, next column) Huang et al. 2003 (PM1.0 more likely to cause lipoperoxidation in human lung cells than larger fractions, OC and EC but not various ions associated with this effect)	Gong et al. 2007 (interaction between oxidized LDL lipids and concentrated ultrafine diesel exhaust particles in Los Angeles air affects gene expression corresponding to atherosclerotic pathways in mice, viewed by authors as confirming in-vitro findings in column to left)	Delfino et al. 2008 (levels of soluble P-selectin, important for platelet activation in atherosclerosis, significantly associated with increased levels of EC of outdoor origin, primary OC, in study of seniors in Los Angeles)

et al. (2005b), Gold et al. (2005), and Creason et al. (2001), in regions such as north-central Pennsylvania or in central New York State, where on most days emissions would reflect little industrial or vehicular emissions relative to urban locations. To be consistent with many of the studies reviewed above, recruitment of those living in a retirement center would be recommended. Would days with higher total $PM_{2.5}$, and/or with higher levels of sulfate, exhibit similar changes in inflammatory indicators (CRP, IL-6), levels of anti-oxidant enzyme activity, or adhesion molecules (soluble P-selectin), as in Delfino et al. (2008)? Such proposed studies should also examine blood pressure and vasoconstriction, as in Auchincloss et al. (2008) and Urch et al. (2004, 2005). ST-segment depression, oxidative stress, and arrhythmias should also be examined in studies paralleling those reviewed above.

Wind trajectory analysis, such as used in Park et al. (2007) and Creason et al. (2001), and which Lippmann et al. (2006) used to demonstrate associations with Ni from Canadian nickel smelters on reduced HRV in mice housed in a rural location in New York State, should also be used to see if on days with elevated measures of health effects the air masses might come from an unsuspected source, as in Lippmann et al. (2006).

These studies would allow a direct comparison with the studies examined in this assessment, and thus would enable researchers to see if ambient coal emissions, including reaction products, would cause the same cardiovascular health effects as diesel and/or vehicular emissions. Recommendation of research of this type, however, is not to recommend that more innovative research is any less important. For instance, the "highway gradient" studies are an example of the kind of innovation that caused researchers to focus on biological mechanisms of vehicular emissions.

More generally, the use of new personal monitoring tools, such as vests being developed by EPA which are easy to wear and monitor many different emissions, may broaden the endpoints which can be examined with regard to pollution associations. Arrhythmias would be one primary endpoint, since up to now, central monitors have been used to provide pollution data in studies of arrhythmias. Since this health endpoint has not yet apparently been examined in studies using accurate exposure information for vehicular emissions, arrhythmias would be an excellent candidate for use in studies with better monitoring, perhaps using the protocols of Schwartz et al. (2005b) and Gold et al. (2005). Furthermore, although V and Ni now tend to be relatively local emissions (e.g., near major ports as shipping fuel and in a few Northeastern locales), it is still important to separate effects of metals from carbonaceous materials.

Conclusions

Epidemiologic studies with good exposure information for locally variable levels of particulate emissions from motor vehicles consistently find associations between such exposure and cardiopulmonary disease mortality, circulatory disease mortality, ischemic heart disease mortality, and all-cause mortality, and with many CV morbidity endpoints, such as cardiovascular hospital admissions, markers of atherosclerosis, survival after heart failure, incidence of

GL14 Continued

coronary heart disease, initial myocardial infarction, and acute myocardial infarction. For each of the cardiovascular health endpoints reviewed herein—oxidative stress, HRV changes, ST-segment depression, inflammation, arrhythmia, vascular function and blood pressure, and atherosclerosis—there are mechanistic studies supporting a pathophysiological basis for how diesel and/or vehicular emissions could cause such outcomes. The mechanistic studies for each endpoint are briefly summarized in Table 3. These cardiovascular health endpoints, in turn, provide multiple biological mechanisms with explanatory value for the mortality and morbidity findings in the epidemiology studies.

A number of the studies reviewed in this paper examined human subjects breathing ambient air. Such studies are likely to provide information most relevant to regulations designed to protect public health. Studies using genetically modified animals and highly concentrated components of ambient air, or using artificial atmospheres, are useful in generating hypotheses, but if these hypotheses are not verified in people exposed to ambient atmospheres, they may not provide an adequate basis for regulation. The database of ambient air studies does provide substantial evidence that the cardiovascular health effects associations with vehicular emissions likely reflect causality, rather than just statistical correlation.

Studies have shown that emissions from diesel engines may be especially potent in producing adverse health outcomes (U.S. Environmental Protection Agency 2002). As of January 2007, EPA regulations require a new catalyzing trap on all new on-road diesels. These devices reduce BC levels virtually completely, while also reducing emissions of many carbonaceous species by large percentages (McDonald et al. 2004). BC is likely an important causal agent of effects with which it has been associated in many studies, both intrinsically and because many carbonaceous species co-emitted from diesels and other vehicles can be adsorbed onto the surface of BC. In addition, BC is also likely a marker for harmful carbonaceous gasses which may be co-emitted with but not adsorbed onto the particles.

The EPA regulations do not extend to retrofits, however, and older diesels are the worst emitters. Several states are taking action to reduce such diesel emissions. In California, there are now proposals to restrict diesels from prior to a particular vintage year from operating in the ports of Los Angeles and Long Beach, unless retrofitted with the new catalyzing trap. Several localities are now requiring retrofit programs on certain classes of vehicles, e.g., school buses, or are advancing the replacement date for older diesel buses. A "speciated" BC standard would be more comprehensive than a patchwork of state requirements, and would likely cause many states to require retrofits of catalyzing traps on older diesels. This would reduce not just BC, but also the associated carbonaceous emissions which adsorb onto BC and also may cause health effects per se. Further, a speciated BC standard would require states to deal with BC in areas not in violation of standards for $PM_{2.5}$, but where diesel health effects would be of consequence to public health. If it made sense to require new technology on new on-road and off-road diesels—and we agree that it does—then it makes even more sense to control emissions from the older, dirtier diesels which will be in operation for perhaps another 30 years.

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ATMOSPHERIC ENVIRONMENT

Review

A review of commuter exposure to ultrafine particles and its health effects

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ABSTRACT

Ultrafine particles (UFPs, <100 nm) are produced in large quantities by vehicular combustion and are implicated in causing several adverse human health effects. Recent work has suggested that a large proportion of daily UFP exposure may occur during commuting. However, the determinants, variability and transport mode-dependence of such exposure are not well-understood. The aim of this review was to address these knowledge gaps by distilling the results of 'in-transit' UFP exposure studies performed to-date, including studies of health effects.

We identified 47 exposure studies performed across 6 transport modes: automobile, bicycle, bus, ferry, rail and walking. These encompassed approximately 3000 individual trips where UFP concentrations were measured. After weighting mean UFP concentrations by the number of trips in which they were collected, we found overall mean UFP concentrations of 3.4, 4.2, 4.5, 4.7, 4.9 and 5.7×10^4 particles cm^{-3} for the bicycle, bus, automobile, rail, walking and ferry modes, respectively. The mean concentration inside automobiles travelling through tunnels was 3.0×10^5 particles cm^{-3}.

While the mean concentrations were indicative of general trends, we found that the determinants of exposure (meteorology, traffic parameters, route, fuel type, exhaust treatment technologies, cabin ventilation, filtration, deposition, UFP penetration) exhibited marked variability and mode-dependence, such that it is not necessarily appropriate to rank modes in order of exposure without detailed consideration of these factors. Ten in-transit health effects studies have been conducted and their results indicate that UFP exposure during commuting can elicit acute effects in both healthy and health-compromised individuals. We suggest that future work should focus on further defining the contribution of in-transit UFP exposure to total UFP exposure, exploring its specific health effects and investigating exposures in the developing world.

1. Introduction

The study of commuter exposure to traffic-related air pollutants is not a particularly new field of research. Among the first researchers to recognise its significance was Professor Arie Haagen-Smit, who is best-known for his pioneering and enduring work related to characterising photochemical smog and ozone. In 1966, he performed a series of carbon monoxide measurements on heavily trafficked Los Angeles roads (Flachsbart, 2007; Haagen-Smit, 1966). Given population growth and increased motor vehicle use since that time, coupled with the high degree of proximity to vehicle emissions when commuting, the issue of 'in-transit' exposure to air pollutants is of equal if not greater relevance 45 years later.

Previous reviews of in-transit pollutant exposure, of which there are few, have focussed on CO inside vehicles (El-Fadel and Abi-Esber, 2009), particle mass concentrations and composition in metro (subway) systems (Nieuwenhuijsen et al., 2007) and various pollutants in multiple transport modes (Weisel, 2001). Only the work of Kaur et al. (2007) included a review of ultrafine (<100 nm) particle (UFP) concentrations in several transport modes.

At present, although gaseous pollutants are still the focus of numerous in-transit exposure studies, UFPs are beginning to attract significant attention. They are produced in large quantities by fuel combustion, and have been identified as a causal component of various negative health effects in humans (Knol et al., 2009; Hoek et al., 2010). UFPs typically constitute ~90% or more of particle number count (PNC) in areas influenced by vehicle emissions (Morawska et al., 2008), and we use UFP to describe PNC throughout this article.

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The primary aim of this review is to distil the results of work performed to-date in order to improve understanding of the measurement, characteristics and determinants of in-transit exposure to UFPs, prior to a discussion of gaps in knowledge and suggestions for future research. Here, we extend the work of Kaur et al. (2007) by confining our focus to UFPs and incorporating the substantial body of relevant work that has appeared in the 4 years since its publication, which now constitutes the large majority of available literature. Like Kaur et al. (2007), we restrict our investigation to UFP exposure concentrations, rather than average or integrated exposure for a given time period. We note that dose assessment, which is a complementary yet distinct concept to that of exposure (Ott, 1985), is not the main focus of this review.

This review begins with an overview of the nature of commuter travel prior to a description of the general characteristics of UFPs. This is followed by a detailed analysis of in-transit UFP exposure studies, a discussion of determinant factors, health effects, and suggestions for future research.

1.1. Commuting in modern society

The nature of modern society in many countries both affords and expects a high degree of personal mobility. Time-activity patterns define how people apportion their time across a range of environments, and are a keystone of effective exposure analyses. Time-activity pattern studies of varying magnitude performed in different regions have reported that time spent in-transit typically constitutes between about 5 and 10% of the day (Klepeis et al., 2001), depending on location. The transport microenvironment(s) within which this time is spent varies more substantially between regions than the occupancy time, and has a greater dependence on local factors, such as the availability and desirability of various transport options.

In general, there are scant 24 h time-activity pattern data for developing countries. Saksena et al. (2007) reported that time spent travelling among 4311 Delhi residents ranged from 0.8 to 10% of the day, and varied markedly depending on age, sex and occupation, as did the mode of transport used. It is likely that the time-activity patterns of people in rural areas differ significantly from those of their urban counterparts.

1.2. Children's and adult's travel choices

Children are particularly susceptible to negative health effects caused by exposure to air pollutants (Gauderman et al., 2004; Brugge et al., 2007; Ashmore and Dimitroulopoulou, 2009), and many millions are required to commute between home and school each weekday. The choice of which transport mode school children utilise is normally at the discretion of others. Whilst children and young people have been reported to possess informed and responsible opinions regarding transport choices and a clear ideal towards cycling and walking, their parent's choices are guided primarily by safety concerns, and place substantial reliance on private automobiles (Lorenc et al., 2008).

Unlike children, adults generally make their own travel choices. A recent survey of 745 employed adults in Queensland, Australia, found that while about half of respondents felt that exposure to air pollutants in-transit negatively affected their overall health and increased their risk of cardiovascular disease, only 13% indicated that exposure to pollutants was a barrier to their adoption of walking or cycling to work, and that other factors were more responsible for their high level (82%) of dependence on private transport (Badland and Duncan, 2009). Furthermore, Badland and Duncan (2009) found that adults who were better educated and lived in urban areas were most cognisant of the negative health effects of air pollutant exposure during transit. Marshall et al. (2009) reported that the optimum balance between high walkability and low pollution was identified sporadically and typically in higher income neighbourhoods in urban Vancouver (Marshall et al., 2009). Evidently, there may be a significant socio-economic component involved in air pollution exposure during transit, particularly for active transport modes, and this may reflect wider socio-economic and environmental inequalities reported for several traffic pollutants (Marshall, 2008; Tonne et al., 2008; Su et al., 2009). It should be noted that both children and adults in developing countries are unlikely to be afforded the luxury of a travel choice, *per se*, and a relatively high degree of dependency on walking and public transport may result from this (Saksena et al., 2007).

2. Characteristics of ultrafine particles

2.1. General

UFP concentrations reflect the contribution of anthropogenic processes to a pre-existing background concentration (Morawska et al., 2008). Background concentrations are ascribed to natural processes, such that in most environments free from the immediate influence of anthropogenic activities, UFPs are present and their concentrations readily measured. Despite the numerous natural sources of UFPs, vehicular fossil fuel combustion has repeatedly been shown to be their dominant source in urban areas, with heavy-duty diesel powered vehicles making a disproportionately large contribution to UFP concentrations (Morawska et al., 2008).

An important distinction is between primary and secondary UFPs. The primary variety are emitted from their source as particles, whilst secondary particles are formed following homogenous nucleation of gases (Koutrakis and Sioutas, 1996; Jacobson, 2002). This occurs when a gas, or gases, nucleate in the absence of a pre-existing surface (Jacobson, 2002).

UFPs from vehicles can be emitted as primary particles or generated as a secondary aerosol, such as following homogenous nucleation of SO_2, NH_3 and NO_x into SO_4^{2-}, NH_4^+ and NO_3^- (Koutrakis and Sioutas, 1996; Morawska et al., 2008). The ratio of primary to secondary particles varies substantially according to fuel type and operating and environmental conditions, but nucleation mode particles can comprise approximately 90% or more of UFPs in diesel exhaust (Kittelson, 1998). However, more recent research indicates that the number of nucleation mode particles in diesel exhaust can be reduced to 40–50% when ultra-low sulphur diesel fuel is used (Ristovski et al., 2006), which is more representative of modern vehicle fleets in many countries.

2.2. Typical concentrations

Morawska et al. (2008) performed a meta-analysis of 71 UFP studies performed across a diverse range of environments. They found mean concentrations of 2.6, 4.8, 7.3, 10.8, 42.1, 48.2, 71.5 and 167.7×10^3 particles cm^{-3} for clean background, rural, urban background, urban, street canyon, roadside, on-road and tunnel environments, respectively. This indicates that greater proximity to vehicles is associated with increased UFP concentrations, and underscores their importance as a UFP source.

2.3. Health significance

Once inhaled, UFPs can reach with the alveolar region of the human lung with greater efficiency than larger particles due to their smaller size, and can deposit in alveoli with greater efficiency as a consequence of their rapid diffusion (Daigle et al., 2003; Phalen et al., 2006; Frampton, 2007). Due to their content of reactive oxygen species (ROS) and large combined surface area, UFPs from vehicle emissions have the potential to damage pulmonary cells (Delfino et al., 2005). Transition metal components in UFPs are believed to play a role in producing ROS, along with pro-oxidative organic hydrocarbons (Li et al., 2003). Additionally, target cells, such as airway epithelial cells and macrophages, produce ROS during biologically catalysed redox reactions occurring in the mitochondria in response to UFP uptake (Li et al., 2003; Nel, 2005). UFPs can evade alveolar macrophage clearance from the lung and enter lung cells, the interstitium and possibly the vascular bed (Geiser et al., 2005; Frampton, 2007), and can travel from the lung via blood and lymphatic circulation to other organs (Elder et al., 2006; Samet et al., 2009). UFPs are more proatherogenic than larger particles due to their greater bioavailability of reactive compounds, content of redox-active compounds, high number concentration and increased lung retention (Araujo and Nel, 2009).

Epidemiologic investigations of UFPs have been constrained by the scarcity of UFP monitoring sites and the substantial spatial heterogeneity of concentrations (Brook et al., 2010). Studies performed to-date in Erfurt, Germany, have indicated that UFP effects on daily mortality may be of comparable magnitude to, yet independent of, those of fine particles (i.e. $PM_{2.5}$), albeit with greater time lag between UFP concentrations and their effects (Wichmann and Peters, 2000). More recent results from the same long-term study have shown statistically significant associations between UFP concentrations and both total and cardio-respiratory daily mortality with a four day lag period (Stölzel et al., 2007). Interestingly, this study found no association between $PM_{2.5}$ mass concentration and mortality. Mortality from stroke amongst aged residents of Helsinki during summer was associated with both $PM_{2.5}$ and UFP concentrations on the previous day, and effects were mostly independent (Kettunen et al., 2007).

The effects of UFP concentration on mortality and morbidity due to various causes are less well understood than those of larger particles. A recent elicitation of European experts found that short-term UFP exposure was rated to variously possess a medium to very high likelihood of causality for all-cause mortality, and a low to high likelihood for cardiovascular and respiratory hospital admissions (Knol et al., 2009). Long-term UFP exposure was generally rated to possess a slightly lower likelihood of causality for all-cause mortality, owing mainly to the lack of long-term studies (Knol et al., 2009). The same group of experts estimated that a permanent decrease in annual average UFP concentration of 1000 particles cm^{-3} across Europe would lead to median decreases of 0.3%, 0.2% and 0.16% in all-cause mortality, and cardiovascular and respiratory hospital admissions, respectively (Hoek et al., 2010). The relatively small number of epidemiological studies (14) and absence of long-term studies, however, resulted in most experts indicating a substantial degree of uncertainty in their estimates (Hoek et al., 2010).

3. Studies of UFP concentration in transport modes

3.1. Methods

We searched combinations of the terms "ultrafine particle", "transport mode", "commuter", "exposure" "public transport", "microenvironment", "vehicle", "car", "automobile", "bus", "cyclist", "bicycle", "train", "metro", "subway" on PubMed, ISI Web of Knowledge and Google Scholar until October, 2010. The reference lists of studies identified by this method were reviewed for links to additional literature. Furthermore, the authors' own literature collections were utilized.

We restricted our investigation to studies that presented numeric values of UFP concentrations, and identified 47 that fulfilled this requirement. Tables S1–S7 in the Supplementary Information file contain detailed information on the various studies. These spanned 6 distinct transport modes: automobile, bus, cycling, ferry, rail and walking. Some studies dealt with multiple transport modes, whilst others focussed on a single mode. Of the studies we identified, only 7/47 (15%) had previously been reviewed by Kaur et al. (2007), which highlights the rapid progression of research related to in-transit UFP exposure since publication of their work.

The mean concentrations extracted from the studies identified were weighted by the corresponding number of trips taken, and overall trip-weighted mean UFP exposure concentrations were calculated for each transport mode (see Tables S1–S7 in the Supplementary Information file). The overwhelming majority of studies (93%) reported the number of trips associated with a given mean; the means reported by those that did not report trip number were weighted by a conservative factor of 1 trip. Most studies reported arithmetic mean UFP concentration, while several reported geometric mean and one gave median values. Where possible, data were disaggregated to permit analyses of the effect of variables such as fuel type, presence of exhaust-treatment devices and route.

Given the range of conditions under which they were collected, we did not assess the statistical significance of differences in measured mean UFP concentrations between modes, and instead sought to identify general trends in the data. This is discussed further in sections 4 and 5.

3.2. Results

Across all modes, we identified approximately 3000 individual trips where UFP measurements were performed. There was an uneven distribution of measurement trips; very few have been performed in ferry (13) and rail (49) modes, while a substantial number have been undertaken in bus (505), walking (524), cycling (599) and automobile (1310) modes. The automobile mode was split into non-tunnel (977) and tunnel (333) trips, as previous results indicate that tunnels are a discrete UFP exposure microenvironment distinct from open air roadways (Kaminsky et al., 2009; Knibbs et al., 2010).

Fig. 1 shows the trip-weighted mean UFP concentrations for each mode, and the number of trips on which they were based. Error bars indicate the trip-weighted standard deviation (Bland and

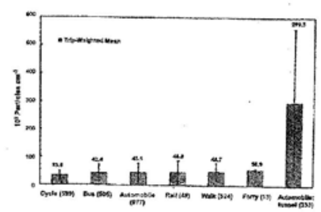

Fig. 1. Trip-weighted mean UFP concentrations in each transport mode, shown as bold numbers. The number of trips taken in each mode is shown in brackets. Error bars denote the trip-weighted standard deviation. The studies from which the data were extracted are listed in the Supplementary Information file.

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Kerry, 1998). The range of mean UFP concentrations spanned one order of magnitude, with the lowest measured whilst cycling and the highest in automobiles during tunnel travel; 3.4×10^4 (s.d. = 1.8×10^4) and 3.0×10^5 (s.d. = 2.6×10^5) particles cm^{-3}, respectively. Means and standard deviations calculated for the automobile (non-tunnel), bus, ferry, rail and walk modes were 4.5 (3.3), 4.2 (3.1), 5.7 (0.5), 4.7 (4.1) and 4.9 (3.2) $\times 10^4$ particles cm^{-3}, respectively.

4. Comparison between modes

Considering the diversity of studies from which they were drawn, the trip-weighted concentrations measured in automobile (non-tunnel), cycle, bus, rail and walking modes exhibited notable coherence, with a maximum to minimum ratio (walk:cycle) of 1.5. A limited number of studies that measured concentrations in different modes simultaneously or near-simultaneously have been reported, and Briggs et al. (2008) found a walk:automobile ratio of 1.4, which is higher than the value of 1.1 presented here. Boogaard et al. (2009) found an automobile:cycle ratio of 1.05, whilst we found a value of 1.3, which was also higher than the value of approximately 1.0 reported by Int Panis et al. (2010).

While the above studies highlighted the relative concentrations encountered in each mode in the absence of bias due to fluctuating UFP concentrations, observed inter-mode contrasts were specific to the conditions of the study (e.g. the ventilation settings in an automobile, or the proximity to traffic on a bike route) and are should therefore not be extrapolated beyond the conditions under which they were collected without appropriate caution.

In studies that measured UFP concentrations in multiple modes non-simultaneously, the mode in which highest concentrations were recorded vacillated between automobiles and buses, whilst those in other modes were markedly lower (Levy et al., 2002; Kaur et al., 2005b; Weichenthal et al., 2008; Cattaneo et al., 2009; Kaur and Nieuwenhuijsen, 2009; Pattinson, 2009; Shrestha, 2009; Knibbs and de Dear, 2010). It is therefore noteworthy that our analysis found that UFP concentrations in buses and automobiles (non-tunnel) were relatively low. We pooled a large number of reported UFP measurements performed under a wide range of conditions, and while the ability to differentiate the observed differences is limited by the level of detail given by the various studies, such an approach is indicative of mean values and general trends. However, the mode in which highest exposures are experienced depends strongly on the determinant factors discussed in the following two sections, and generalisation of results may be of limited value (Int Panis et al., 2010); that is, within mode variability is likely to be substantial.

5. Determinants of UFP concentration in-transit

Despite the convenience it may provide, it is not necessarily appropriate to rank transport modes in order of UFP exposure without certain caveats. For example, Fig. 1 shows the trip-weighted mean UFP concentration in an automobile is higher than the equivalent for cycling. However, an occupant of a relatively air-tight automobile in which air is recirculated and filtered will likely experience markedly lower exposure concentrations than a cyclist on a high traffic route. Disentangling the relative roles of determinant factors, their interactions and variability in each mode is a key element required to advance understanding of in-transit UFP exposure. The data reviewed here suggest that while the relationship between UFP concentration and its determinants is often mode-dependent, exposure in all mode types is the result of interplay between multiple factors. These can be viewed as comprising two stages: the first determines the outdoor or on-road UFP concentration, and the second determines what proportion of this is able to come into contact with a commuter. These factors are addressed, in turn, in the following sections.

5.1. Meteorological variables

Temperature has been variously reported to be positively and negatively correlated with UFP concentrations, although in vehicle-dominated areas the correlation is more likely to be negative due to condensation of volatile compounds in emissions (Morawska et al., 2008). In-transit studies that assessed this relationship uniformly found a negative correlation between temperature and UFP concentration (Krausse and Mardaljevic, 2005; Vinzents et al., 2005; Thai et al., 2008; Weichenthal et al., 2008; Kaur and Nieuwenhuijsen, 2009; Pattinson, 2009; Laumbach et al., 2010). Among studies that reported correlation coefficients, those measured for cycling studies (Vinzents et al., 2005; Thai et al., 2008) were quite high (−0.62 and −0.76, respectively). Multi-mode and automobile studies reported correlations of −0.77 and −0.37, respectively (Kaur and Nieuwenhuijsen, 2009; Laumbach et al., 2010).

Wind speed, which affects dilution and transport of vehicle emissions, was also found to be negatively correlated with UFP concentration in-transit (Krausse and Mardaljevic, 2005; Vinzents et al., 2005; Briggs et al., 2008; Thai et al., 2008; Weichenthal et al., 2008; Kaur and Nieuwenhuijsen, 2009; Pattinson, 2009; Shrestha, 2009; Knibbs and de Dear, 2010), which is in agreement with results reported for various outdoor locations (Morawska et al., 2008). However, the results were not always statistically significant, indicating that temperature may be more consistently and strongly correlated with UFP concentrations. Correlations observed for active transport modes were −0.20 (walk), −0.52 (cycle) and −0.81 (cycle) (Briggs et al., 2008; Vinzents et al., 2005; Thai et al., 2008). Multi-mode and automobile studies reported correlations of −0.14 to −0.49 (Briggs et al., 2008; Kaur and Nieuwenhuijsen, 2009; Knibbs and de Dear, 2010).

For both temperature and wind speed, stronger correlations were generally observed for cycling compared to non-active modes, perhaps reflecting reduced influence of other factors on exposure concentrations encountered when cycling (and walking). The strength of the association between UFP concentration and both temperature and wind speed appears to be mode and location-dependent, and its variability is not well characterised.

While temperature and wind speed are the most frequently reported, other meteorological parameters may affect UFP concentration. The depth of the mixed layer within the atmosphere was found to be negatively correlated with in-transit UFP concentration (Weichenthal et al., 2008), which reflects the tendency of a shallow mixed layer to concentrate pollutants.

5.2. Traffic volume and composition

Very few studies have reported the relationship between traffic volume and in-transit UFP concentrations. Fewer still have examined the effect of traffic composition (i.e. gasoline vehicles, diesel vehicles). Briggs et al. (2008) observed statistically significant correlations between car and truck density and UFP concentrations encountered while walking (r = 0.41–0.48) or in an automobile (r = 0.43–0.47) in London. In their London-based study, Kaur and Nieuwenhuijsen (2009) similarly found a significant correlation (ρ = 0.27) between total traffic count and UFP concentrations in automobile, bus, cycle, taxi and walking modes. Krausse and Mardaljevic (2005) reported road link end description (e.g. signal, left turn, right turn etc.) was a significant determinant of total UFP exposure of car occupants. On-road studies have shown strong

associations (R^2 ~ 0.85) between heavy diesel traffic volume and UFP concentrations (Fruin et al., 2008; Knibbs et al., 2009b). Other studies have reported more qualitative, assessments of traffic effects; for example, that mean in-transit UFP concentrations increased on high traffic routes and vice-versa (Zhu et al., 2007; Thai et al., 2008; Strak et al., 2010; Zuurbier et al., 2010).

Vehicle emissions are the dominant source of UFPs in urban areas, and heavy diesel vehicles make a contribution that is disproportionate to their volume (Morawska et al., 2008). Coupled with the limited but consistent findings of in-transit studies, this suggests that traffic parameters (volume, density) and composition (gasoline vehicles, heavy diesel vehicles) are an important determinant of in-transit UFP exposure. It should be considered, however, that effects are likely to depend on mode, and that short-term traffic patterns not represented in hourly or daily average data, such as the impact of passing traffic, may be important (Fruin et al., 2008; Boogaard et al., 2009).

5.3. Route choice: active transport modes

There are generally fewer mode-specific variables that may affect pedestrians and cyclists compared to other transport modes; that is, traffic and meteorological conditions may be of greater importance as determinants. Most cycling studies were performed on or proximate to major urban roads, however, some studies compared measurements on high and low traffic routes, with the latter typically comprised of a dedicated cycle path. Separating the data into these two categories revealed that 18% of trips were undertaken on low traffic routes, and mean UFP concentrations were 2.6×10^4 particles cm^{-3}. The mean for high traffic routes was 3.5×10^4 particles cm^{-3}, suggesting that route selection, within the context of the few studies to address it, can affect cyclist UFP exposure (Pattinson, 2009; Strak et al., 2010; Zuurbier et al., 2010).

Route choice, as a proxy for traffic volume, is likely to be an important determinant of exposure (McCreanor et al., 2007; Hertel et al., 2008), and personal factors (e.g. walking or cycling patterns) may also exert an effect (Kaur et al., 2007). Microscale variations in UFP concentration proximate to roadways may result in higher exposures on the road side of the sidewalk/footpath compared to the building side (Kaur et al., 2005a). Also, the effect of roadway factors on pollutant dispersion (i.e. whether open to the environment or prone to trap pollutants due to geometry of urban canyons) has been shown to be a statistically significant determinant of UFP exposure concentrations encountered when walking (Briggs et al., 2008). Further work focussed on evaluating the effects of these local and microscale route phenomena on UFP exposure is required.

5.4. Cabin ventilation

Ventilation rates, whether driven by fans, natural leakage or open windows (Ott et al., 2008; Knibbs et al., 2009a), describe how rapidly outdoor air is capable of entering passenger cabins. Evidence suggests that ventilation is a key determinant of in-cabin UFP concentrations in automobiles, buses (Hammond et al., 2007; Rim et al., 2008; Knibbs and de Dear, 2010; Zhang and Zhu, 2010), ferries (Hill and Gooch, 2007; Knibbs and de Dear, 2010) and rail modes (Hill and Gooch, 2007; Cheng et al., 2009; Knibbs and de Dear, 2010). Quantitative studies support these observations, but are scarce and limited to automobiles (Xu and Zhu, 2009; Knibbs et al., 2010).

Knibbs et al. (2009a) found that air exchange increased linearly with vehicle speed in a group of six test automobiles operating under four distinct ventilation settings, which was in agreement with results obtained by Ott et al. (2008) based on tests performed in four vehicles. Knibbs et al. (2009b, 2010) found that the primary determinant of on-road UFP concentration in a tunnel bore was hourly heavy diesel vehicle volume (R^2 = 0.87), and that cabin ventilation rates explained 81% of the variation in the proportion of on-road UFPs reaching the occupants of 5 automobiles. The proportion reaching the cabin varied from 0.08 (recirculation) to ~1.0 (non-recirculation) depending on vehicle and ventilation setting. Thus, ventilation rates controlled the extent to which in-cabin exposure concentrations reflected on-road levels in the tunnel bore, which were largely determined by heavy diesel vehicle volume. Xu and Zhu (2009) reported that cabin ventilation and leakage were predominant factors in their model-based analyses of variables affecting in-cabin/on-road (I/O) UFP ratios, and explained up to ~60% of on-road UFP ingress. I/O ratios when windows are open can reach 1 due to higher air exchange, and such conditions may also occur when windows are closed but ventilation fan settings are high (Ott et al., 2008; Knibbs et al., 2009a).

Some investigators have successfully performed in-cabin UFP size distribution measurements during transit in automobiles (Zhu et al., 2007) and buses (Zhang and Zhu, 2010). These studies have shown that while in-cabin particle size distributions follow the general shape of those on-roads, the ability of on-road particles to reach the cabin is dependent on particle size and ventilation settings (Zhu et al., 2007). Particle penetration is discussed in section 5.6.

5.5. Filtration

Where a vehicle is fitted with a cabin air filter, its efficiency is a key determinant of what proportion of on-road UFPs reach the cabin, and efficiency varies substantially amongst the filters available. Standard automobile cabin filters afford single-pass UFP reductions of between approximately 30 and 60% (Pui et al., 2008; Qi et al., 2008), while this can increased by employing more advanced filtration technologies (Burtscher et al., 2008). It should be noted that filtration efficiency is affected by the ventilation rate; as filter face velocity increases with mechanical or natural ventilation rates, filtration efficiency decreases due to the reduced time available for particle diffusion inside the filter (Pui et al., 2008; Qi et al., 2008). When air is recirculated in an automobile, Qi et al. (2008) found that UFP concentrations decayed most rapidly in a vehicle capable of filtering recirculated air (single pass efficiency = 46%) than in a vehicle lacking this feature, where UFP removal efficiency without a filter was 27% per recirculation of cabin air. In the former and latter cases, on-road UFP concentrations were reduced to those typical of an office building (4000 particles cm^{-3}) in 3 min and 9–10 min, respectively, indicating the value of recirculation as a simple exposure minimisation mechanism. However, some older, less-airtight vehicles are characterised by outdoor air exchange rates up to 47 h^{-1} when air is recirculated (Knibbs et al., 2009a), and the benefit of recirculation in such cases can be substantially diminished (Knibbs et al., 2010).

5.6. UFP penetration and deposition

The penetration of UFPs through automobile envelopes is dependent on their size, the number and geometry of cracks, and the pressure difference across these and other ingress pathways (Xu et al., 2010). A recent study reported that penetration efficiency close to 100% was observed for diesel exhaust particles between 100 and 287 nm, and declined to ~70% for 10 nm particles due to diffusion; although penetration of 10 nm particles increased to ~90% when pressure differentials reached 200 Pa (Xu et al., 2010). No difference was observed in penetration efficiency amongst different materials.

GL14 Continued

GL14 Continued

Given the high surface to volume ratios of many automobile cabins, deposition can be an important UFP removal mechanism, especially under low ventilation conditions (Gong et al., 2009). Gong et al. (2009) found in-cabin deposition rates in automobiles exceed those of indoor environments by a factor of 3–20.

Studies describing UFP filtration, penetration and deposition in bus and rail modes are scarce and the limited data to-date is strongly skewed towards automobiles. Future studies addressing this knowledge gap will be of considerable value.

5.7. Fuel type and presence of an emission control device

5.7.1. Automobile

The effect of fuel type on UFP concentration in automobiles was assessed by Zuurbier et al. (2010), who found no significant difference in mean levels in diesel and gasoline-powered vehicles (diesel:gasoline concentration ratio = 0.96) based on 14 simultaneous trips under a standard ventilation setting. Their study focussed only on newer vehicles (<6 months) and its relevance to the wider passenger vehicle fleet is unknown. Additionally, it is difficult to separate the effects of fuel type from those due to differences in ventilation under a standard setting between vehicles of different manufacturer (e.g. Knibbs et al., 2009a). Further studies involving test vehicle groups more representative of the heterogeneity present in wider vehicle fleets are required.

5.7.2. Bus

Due to their frequency of door opening and the 'stop-start' nature in which they travel, buses have a tendency to self-pollute (Behrentz et al., 2004; Hill et al., 2005; Rim et al., 2008; Liu et al., 2010; Zhang and Zhu, 2010; Zuurbier et al., 2010). Accordingly, the variables most frequently reported by UFP exposure studies were fuel type and the presence of an exhaust or crankcase emission control device. We therefore disaggregated bus trips into 8 categories: diesel, biodiesel, compressed natural gas (CNG), electric, diesel with oxidation catalyst (DOC), diesel with diesel particulate filter (DPF), diesel with crankcase filtration system (CFS), and diesel with combined control (i.e. any combination of two or more of DOC, DPF, CFS and ultra low sulphur diesel). About 70% of trips were performed in diesel buses, with the remainder approximately evenly distributed across the other categories. Five percent of bus trips (26/506) were excluded due to lack of detailed data on fuel type or control device.

Fig. 2 shows the trip-weighted mean UFP concentrations for each category. The lowest mean (1.7×10^4 particles cm^{-3}; $SD = 0.8 \times 10^4$) was recorded in CNG-powered buses, and the highest (4.9×10^4 particles cm^{-3}; $SD = 2.6 \times 10^4$) was measured in diesel buses fitted with a CFS, although the latter result was based on a very limited number of trips (13). A similar mean was recorded in diesel buses with no control device (4.8×10^4 particles cm^{-3}; $SD = 3.2 \times 10^4$). Means and standard deviations calculated for the biodiesel, combined control, DPF, DOC and electric categories were 1.7 (–), 2.0 (1.8), 2.4 (0.9), 2.8 (2.0) and 2.9 (0.8) $\times 10^4$ particles cm^{-3}, respectively. With the exception of the electric bus category, lowest concentrations were measured in buses powered by alternative fuels. Concentrations inside diesel-powered buses were generally lower when fitted with an emission control device.

Differentiating the effects of self-pollution from those of other factors on in-bus UFP concentrations is challenging. Previous work has shown that self-pollution can be the dominant source of vehicle emissions in the cabin when windows are closed, and constituted 0.01 to 0.3% of air in the cabins of 1975 through 2002 model school buses (Behrentz et al., 2004). Liu et al. (2010) found that self-pollution contributed an overall average of 1.8×10^4 particles cm^{-3} in two school buses (2000 and 2003 model); the average

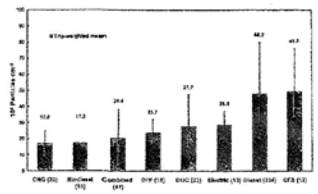

Fig. 2. Trip-weighted mean UFP concentrations measured in buses of different fuel type and emission control device. The number of trips taken in each category is shown in brackets. Error bars denote the trip-weighted standard deviation. See text for abbreviations.

contribution when windows were closed (1.0×10^4 particles cm^{-3}) was less than that when they were open (2.6×10^4 particles cm^{-3}). However, this trend was not in keeping with their results for other measured pollutants, and was attributed to UFP fluctuations due to unidentified non-vehicle sources on the low-traffic routes they studied. Generally, if on-road concentrations are low relative to those in-cabin, open windows will dilute self-pollution (Liu et al., 2010). The reverse can exacerbate its effects.

The relatively small number of trips taken in most categories we analysed and the lack of specific information regarding other possible determinants limits the conclusions that can be drawn, and precluded detailed statistical analyses. However, the results generally suggest that UFP concentrations are greatest in diesel-powered buses, and that reductions may be possible through use of alternative fuels or emission control devices, with best results achieved for diesel buses when two or more of the latter are combined.

5.7.3. Rail

In most rail studies we identified, trips were undertaken in vehicles driven by electricity. About 29% of trips were taken in diesel-powered trains, and the weighted mean UFP concentration during these was 9.0×10^4 particles cm^{-3}. The mean during travel in electric-powered vehicles was 3.0×10^4 particles cm^{-3}. Based on the limited data available, the power source of the rail vehicle therefore appears to markedly affect UFP exposure concentrations. Moreover, in diesel trains, the position of the locomotive relative to the passenger compartments can affect UFP concentrations: when a locomotive was located in front of passenger cabins, its emission plume can reach the cabin ventilation system intake Hill and Gooch, 2007.

There was insufficient data to investigate the effect of underground and above ground travel on UFP concentrations. Whilst there are numerous mechanical processes that can generate and resuspend particulate matter in electric-powered subway/metro systems, these are more likely to elevate levels of particle mass rather than UFP number count (Nieuwenhuijsen et al., 2007). The limited number of studies reporting UFP measurements on underground platforms tend to support this (Aarnio et al., 2005; Seaton et al., 2005; Raut et al., 2009; Cheng et al., 2009; Nystrom et al., 2010).

6. Correlation with other air pollutants

Several in-transit studies measured UFPs and other pollutants simultaneously. A summary of these is provided in Table S8 in the

Supplementary Information file. The correlation between UFP and $PM_{2.5}$ concentrations is generally reported to be positive, weak and not statistically significant, although stronger associations have been observed; correlation coefficients range from −0.07 to 0.69 (Aarnio et al., 2005; Kaur et al., 2005a,b; Seaton et al., 2005; McCreanor et al., 2007; Zhu et al., 2008; Berghmans et al., 2009; Boogaard et al., 2009; Knibbs and de Dear, 2010; Laumbach et al., 2010). Although correlation in the rail mode is moderate and relatively consistent across studies, in general there is no clear relationship between the strength of correlation and transport mode. The results are likely to be somewhat location-dependent, in keeping with those for outdoor environments, and the generally poor correlation reflects differences in the sources of particle number and mass and temporal scales involved in their dynamics (Morawska et al., 2008).

Black carbon (BC) and elemental carbon (EC) are often well-correlated with UFP concentrations in urban air, given their shared provenance in vehicle emissions and the large extent to which BC and EC contribute to UFP chemical composition (Morawska et al., 2008). On-road and subway platform studies have shown very good correlation between UFPs and BC; 0.88 and 0.84, respectively (Aarnio et al., 2005; Westerdahl et al., 2005). Correlations were relatively weak in automobile and bus studies (mean = 0.1–0.2), although in-bus relationships were strongly dependent on window position, and mean correlation improved (mean = 0.62) when windows were kept open, which the authors ascribed to self-pollution under the closed window setting (Zhu et al., 2008; Zhang and Zhu, 2010). Very good correlations between UFPs and EC (0.70 and 0.84) have been reported in walking studies (Kaur et al., 2005a; McCreanor et al., 2007).

The correlation between UFP concentrations and those of NO_x vary extensively from −0.33 to 0.90, and no clear relationship with transport mode is apparent (Westerdahl et al., 2005; McCreanor et al., 2007; Zhu et al., 2008; Laumbach et al., 2010). The relationship with CO concentrations is similarly variable; −0.16 to 0.70 (Kaur et al., 2005a,b; Westerdahl et al., 2005; McCreanor et al., 2007; Zhu et al., 2008; Laumbach et al., 2010). The specifics of the measurement location in terms of local emission sources are likely to explain the observed variation, and it is important to consider that in-transit measurements of particle and gaseous pollutants may exhibit poor temporal correlation due to the varying emission strength of proximate vehicles (Morawska et al., 2008; Zhu et al., 2008).

In summary, the relationship between in-transit UFP concentrations and those of other pollutants is generally inconsistent. Mode, location and environmental factors may all contribute to the observed variability, and the results gathered here from the limited pool of available studies require further validation in order to develop a more complete understanding of the associations. Currently, there is no data to support prediction of UFP concentrations from those of other pollutants, and such an approach is likely to be insufficient.

7. Relationship with fixed site monitors

Since the 1970s (Ott and Eliassen, 1973; Cortese and Spengler, 1976), numerous studies have investigated the ability of fixed site pollutant monitoring stations to estimate personal and commuter exposure. Generally, the ability of fixed site monitors to represent the substantial spatial and temporal variability of in-transit exposures has been sub-optimal, and carries with it numerous attendant limitations, the most important of which is underestimation of exposure (Kaur et al., 2007). UFPs are not a regulated pollutant, and are therefore not routinely monitored outside of research studies. Some investigators have assessed the association between fixed site UFP concentrations and those measured concurrently in-transit.

Aarnio et al. (2005) reported good correlation ($R^2 = 0.59$) between UFP concentrations in subway stations and those measured at an urban background site, while Seaton et al. (2005) found that the ratio of UFP concentrations measured on London Underground platforms to those above ground ranged from 0.38 to 0.68. These results are likely to reflect the absence of strong local UFP sources in subways (Aarnio et al., 2005). For above ground transport microenvironments, however, this is unlikely to be the case. Vinzents et al. (2005) reported a moderate correlation ($r = 0.49$) between UFP measurements performed at a fixed roadside location and those measured while cycling, but found that the only significant variables in a linear mixed effects model to predict cyclist exposure were temperature and concentrations of CO ($R^2 = 0.60$) and NO_2 ($R^2 = 0.74$) measured at urban background and roadside stations, respectively. Asmi et al. (2009) found that the ratio of UFP concentration in the driver's cabin of buses to that measured at an urban background site varied from 1.2 to 6.9 and was dependent on the age of the bus, time of day and route. Zuurbier et al. (2010) systematically evaluated the relationship between bus, car and bicycle UFP exposures and urban background concentrations in Arnhem, the Netherlands. They reported median mode to background ratios of 1.6 (diesel car, electric bus) to 2.5 (diesel bus) and correlations between 0.01 (diesel bus) and 0.87 (bicycle on low-traffic route).

The limited data available to-date indicates that fixed-site monitors may offer some ability to estimate UFP exposure of commuters in areas less affected by vehicle emissions, such as those using subways or low-traffic bike paths. However, depending on location, such persons are likely to constitute only a minor proportion of the commuting population. In the absence of widespread UFP monitoring networks, the utility of routinely monitored particle and gaseous pollutants or individual UFP monitors to represent in-transit UFP exposure appears significantly constrained (Krausse and Mardaljevic, 2005; Vinzents et al., 2005).

8. Health effects of in-transit UFP exposure

Studies of health effects due to commuter UFP exposure are summarised in Table S9 in the Supplementary Information file.

8.1. Healthy individuals

Nystrom et al. (2010) showed that while a cellular response in the airway epithelium was not elicited, minor biological responses such as increased systemic markers of inflammation and signs of lower airway irritation were observed in 20 healthy individuals exposed to subway air (mean UFP concentration 1.1×10^4 particles cm^{-3}) for 2 h while alternating between exercising on a bicycle ergometer and resting. However, road tunnel air (median UFP concentration 1.1×10^5 particles cm^{-3}) elicited an inflammatory response in the lower airways and elevated levels of T-lymphocytes and alveolar macrophages in brochoalveolar lavages from 16 healthy individuals who followed the same protocol (Larsson et al., 2007). The particle mass concentrations that subjects were exposed to in the two above studies were similar, while UFP and NO_x concentrations were an order of magnitude higher in the road tunnel study than in the subway study due to the presence of proximate vehicle emissions. Although it is not possible to ascribe the disparity in the results of the two studies to differences in UFP concentration alone, the results are suggestive of a causative role for UFP and NO_x in airway inflammation observed following exposure to vehicle emissions.